United States Patent

Keith

[15] **3,636,637**

[45] **Jan. 25, 1972**

[54] METHOD AND APPARATUS FOR DRYING LIQUID DEPOSITED ON LIQUID RECEPTIVE MATERIAL

[72] Inventor: **Charles N. Keith**, Bedford, Tex.

[73] Assignee: **Graphic Pollution Control, Inc.**, Irving, Tex.

[22] Filed: **May 6, 1970**

[21] Appl. No.: **35,146**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 1,030, Jan. 6, 1970, abandoned.

[52] **U.S. Cl.** **34/1**, 219/10.81

[51] **Int. Cl.** **B01k 5/00**

[58] **Field of Search** 34/1; 219/10.81

[56] **References Cited**

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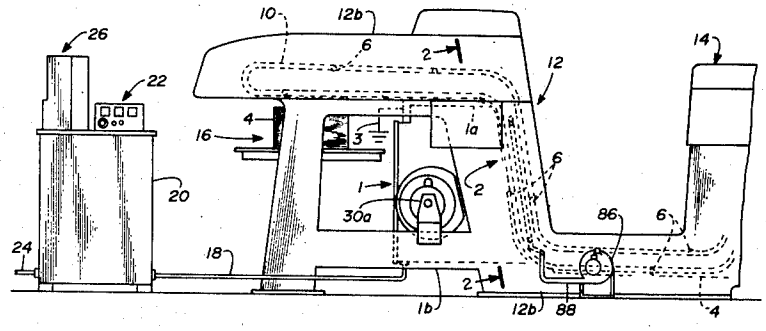
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Primary Examiner—Charles Sukalo
Attorney—Richards, Harris & Hubbard

[57] **ABSTRACT**

An electronic dryer for setting ink comprising spaced electrodes of an antenna radiating a high potential radiofrequency electromagnetic field through which is passed a liquid receptive material, such as paper, having wet ink thereon. A shield of dielectric material is positioned to extend between the electrodes to prevent arcing between the electrodes. In addition, ionized air around the electrodes is removed to further minimize the possibility of interelectrode arcing. A static electricity eliminator is employed to generate an electromagnetic field for removing static charges from the paper to prevent arcing between the paper and the electrodes.

28 Claims, 32 Drawing Figures



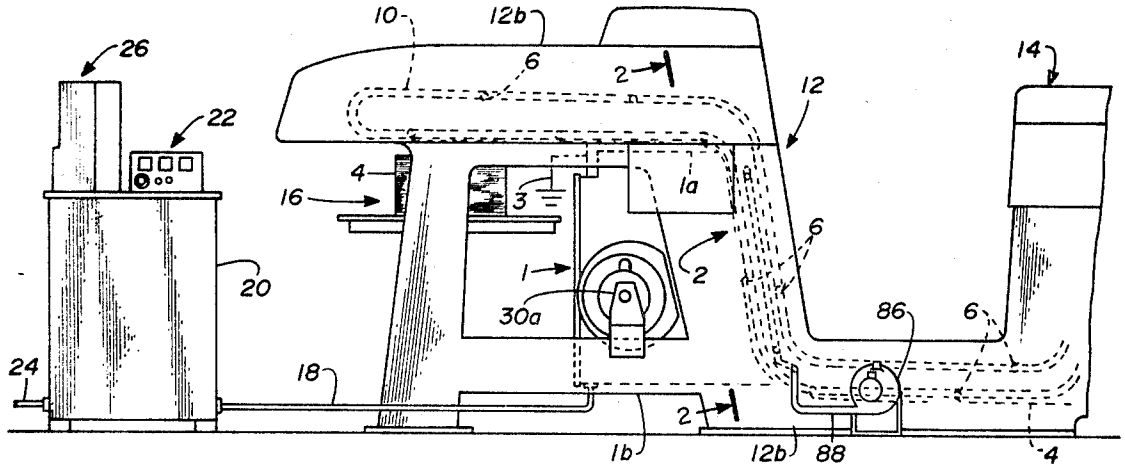

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FIG. 1

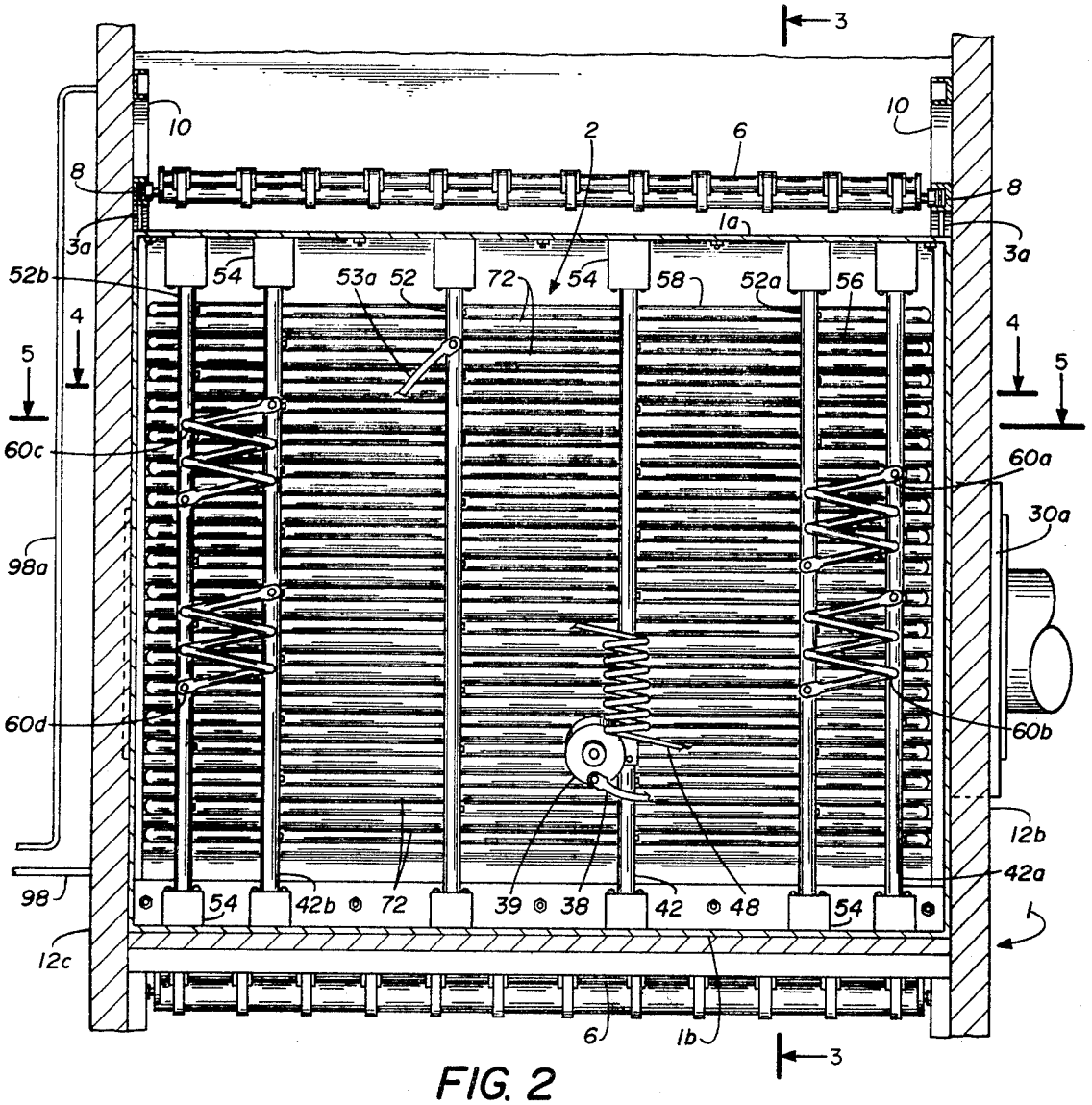

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FIG. 2

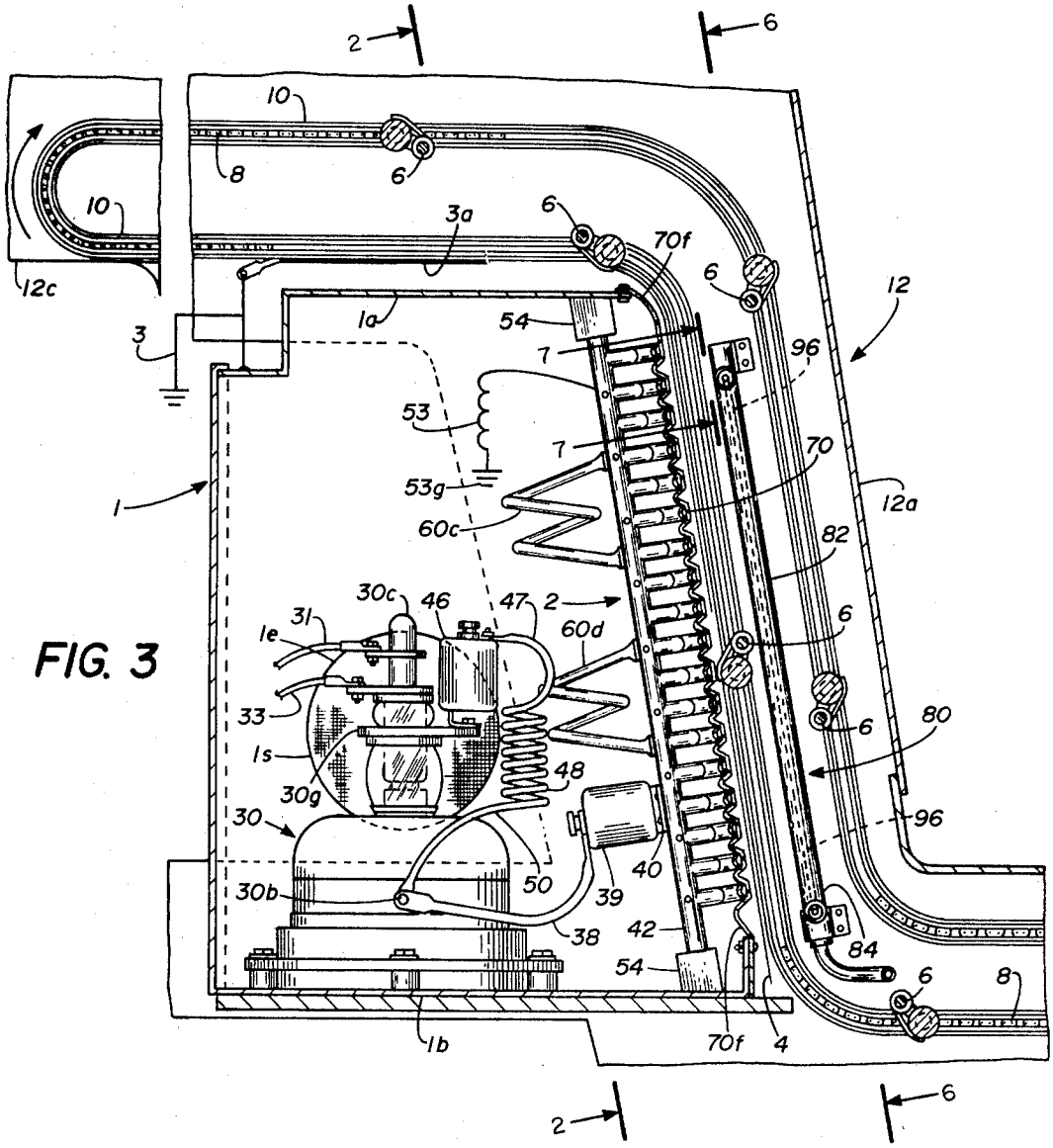

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FIG. 3

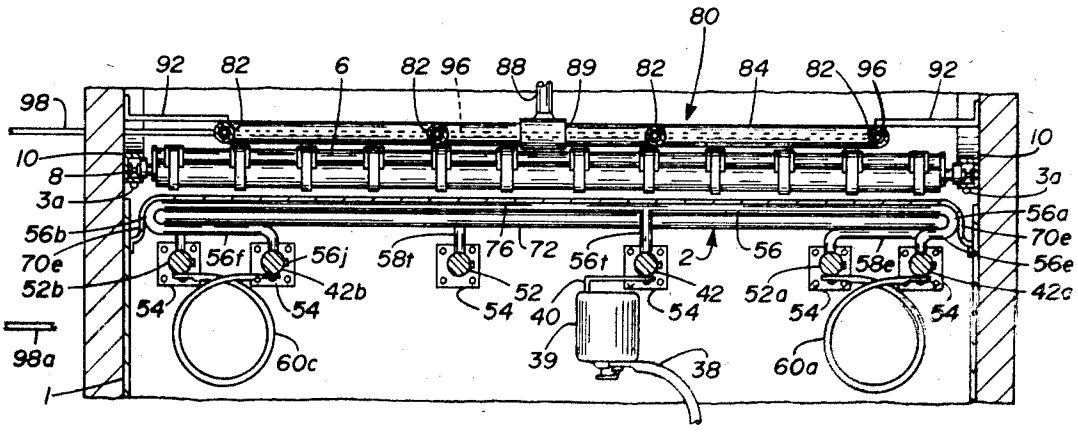

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FIG. 4

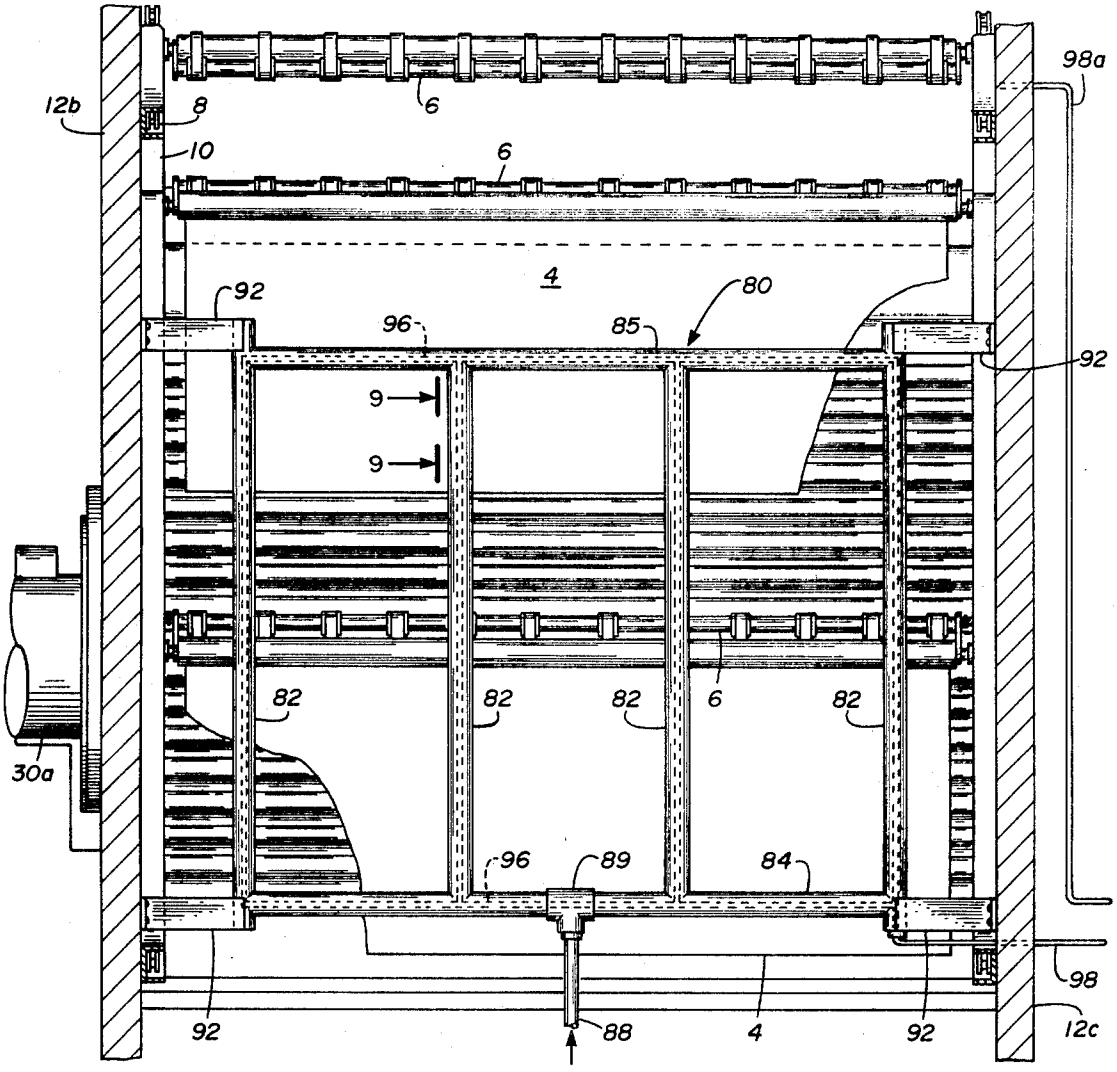

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FIG. 6

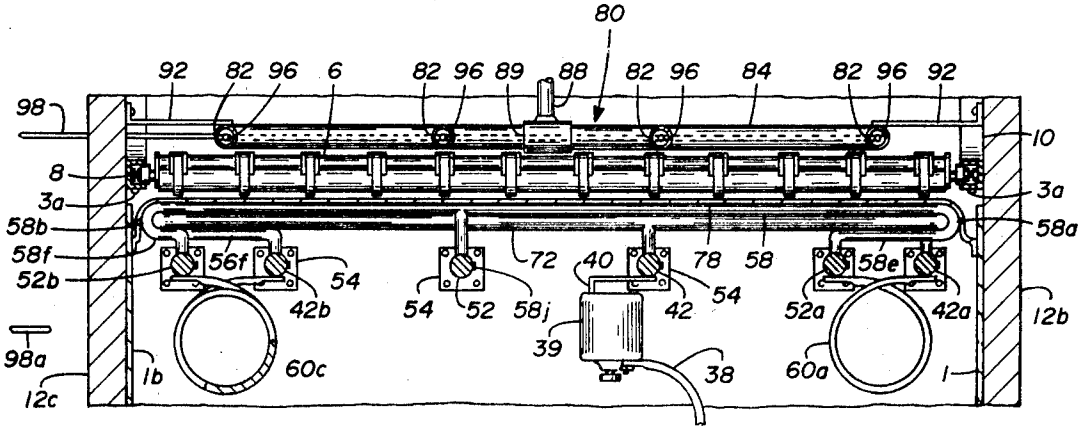

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FIG. 5

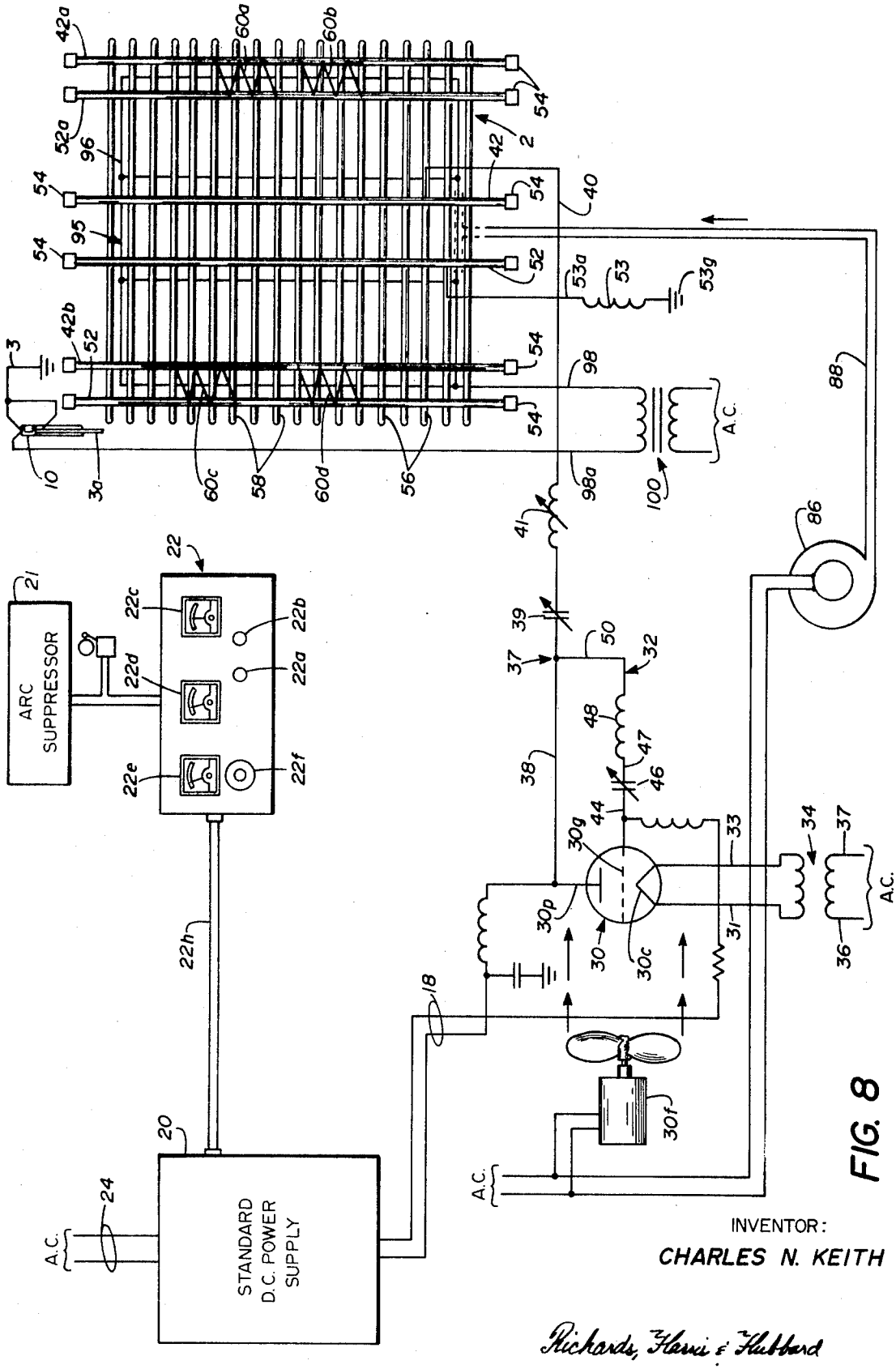


FIG. 8

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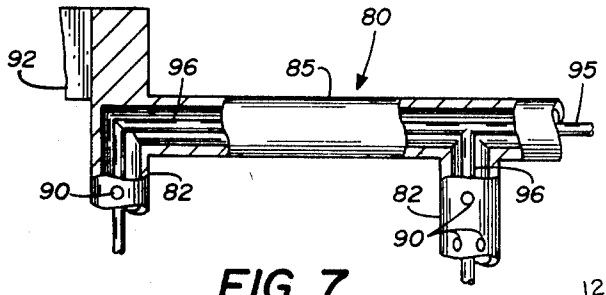


FIG. 7

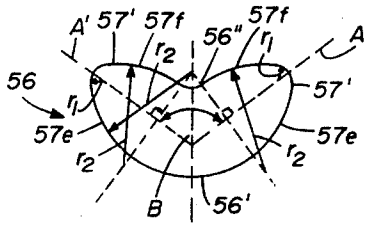


FIG. 10

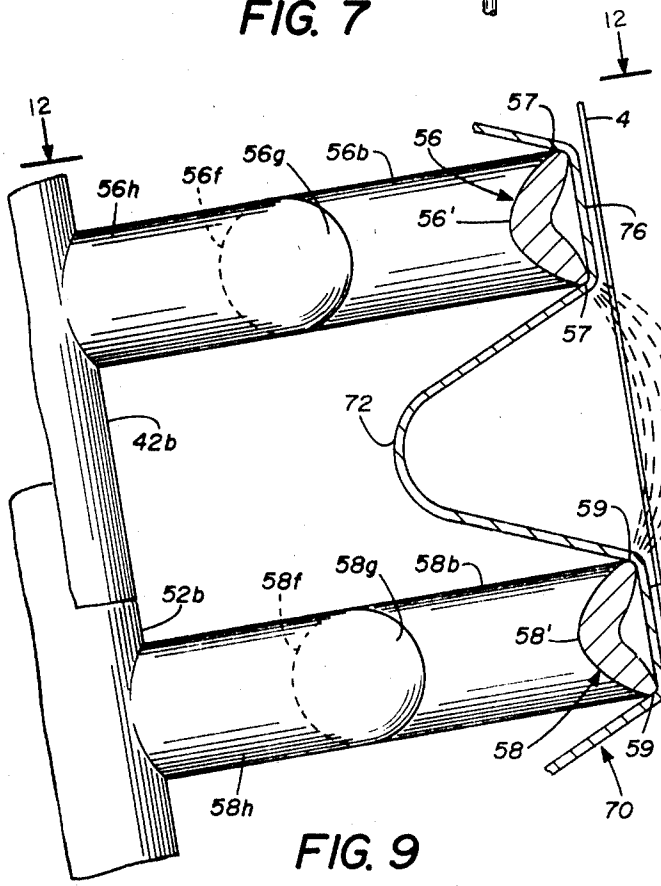


FIG. 9

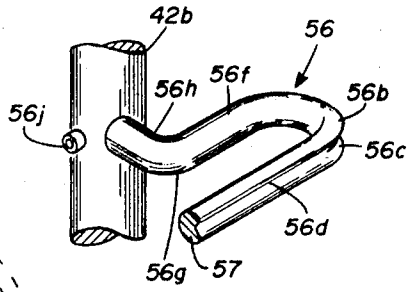


FIG. 11

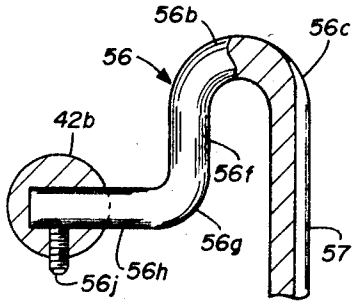


FIG. 12

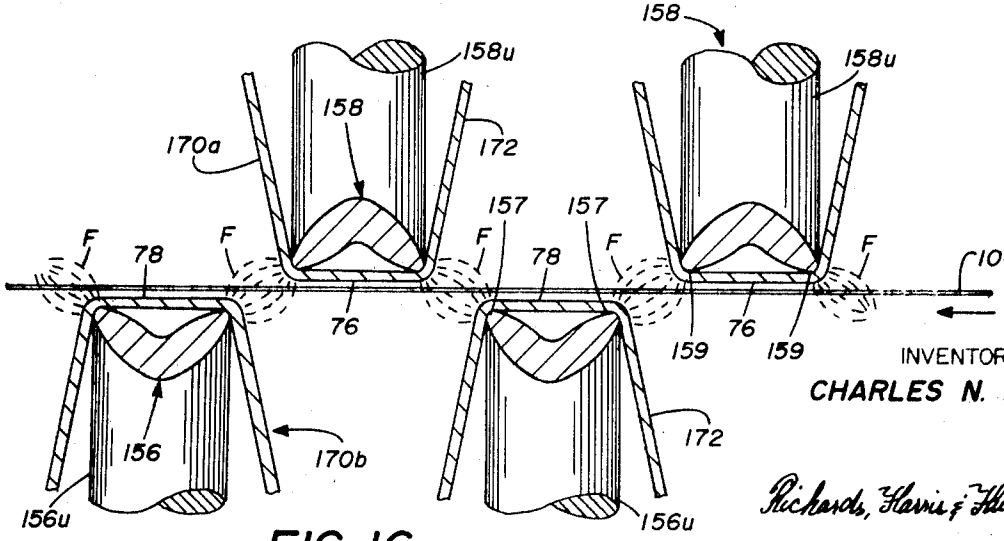


FIG. 16

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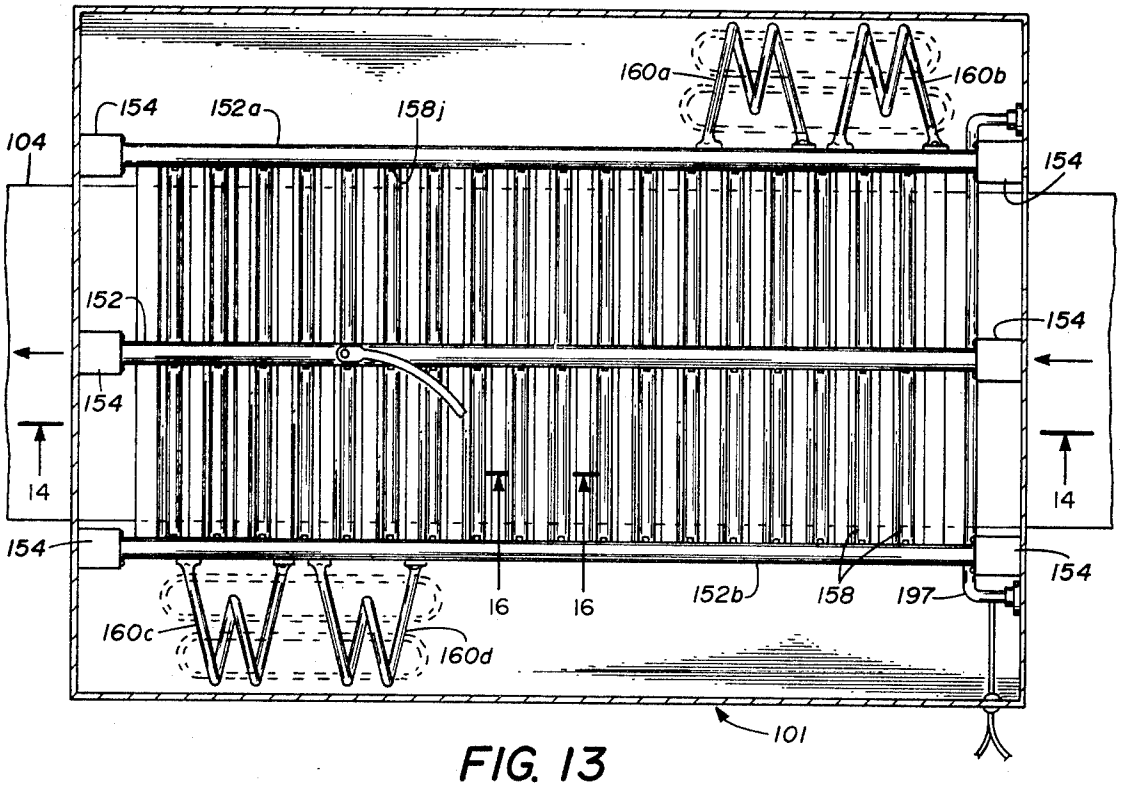


FIG. 13

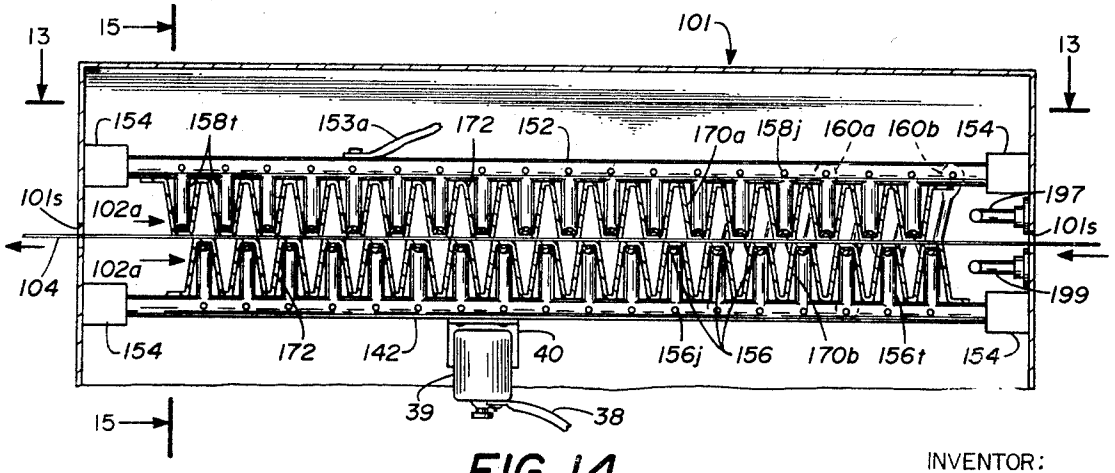


FIG. 14

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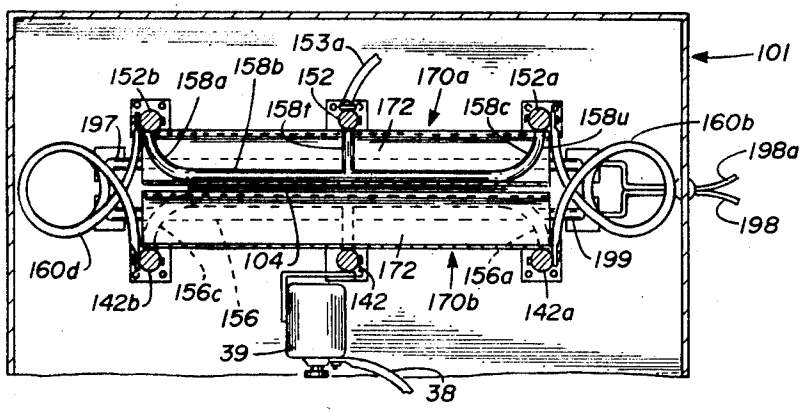


FIG. 15

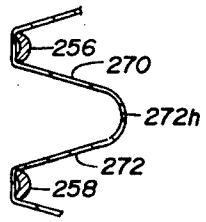


FIG. 21

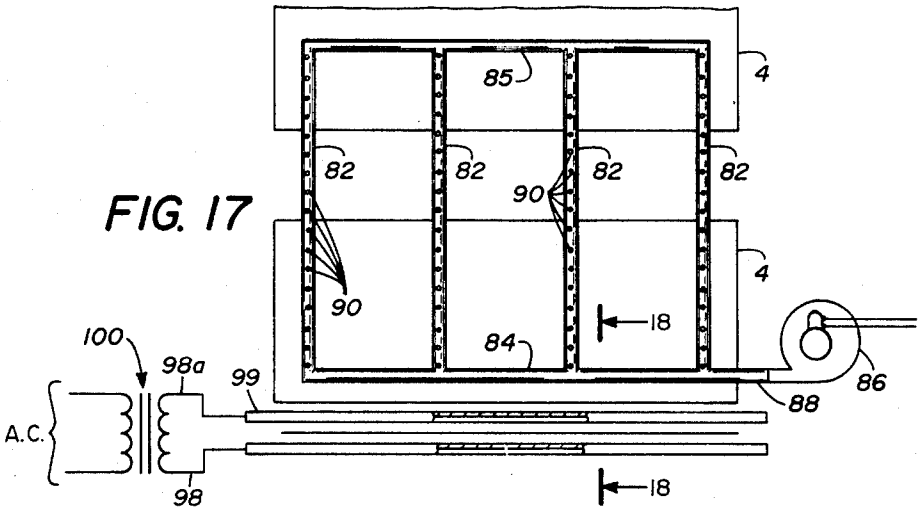


FIG. 17

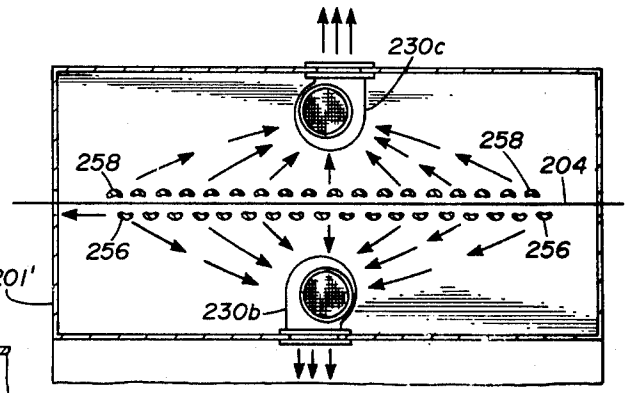


FIG. 20

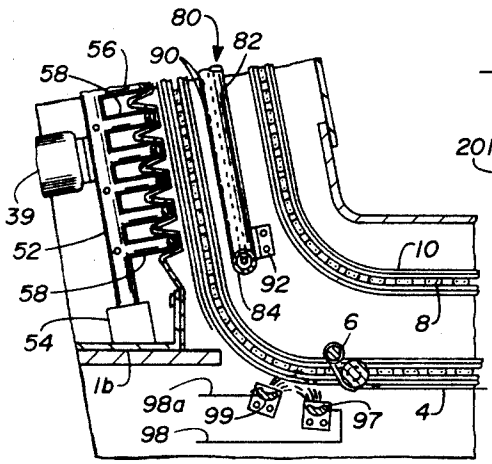


FIG. 18

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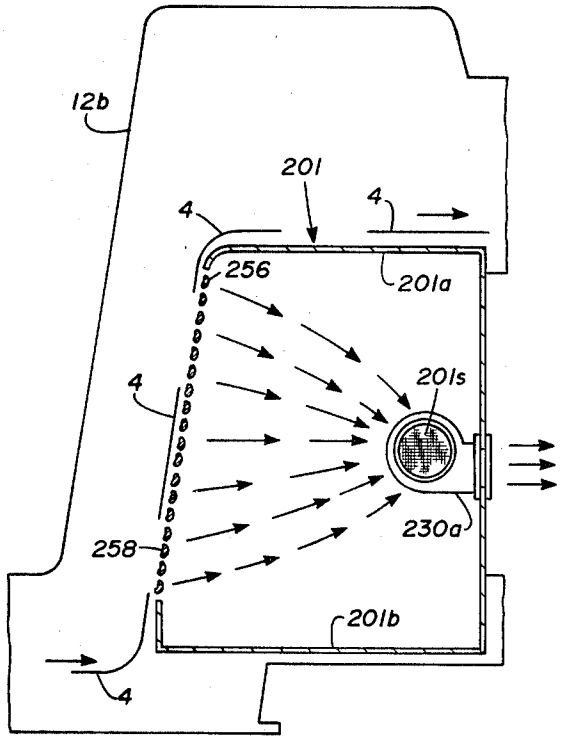


FIG. 19

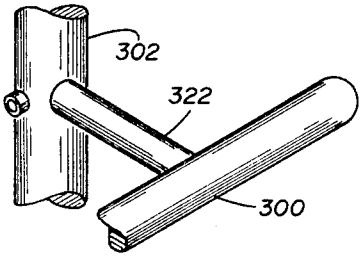


FIG. 26

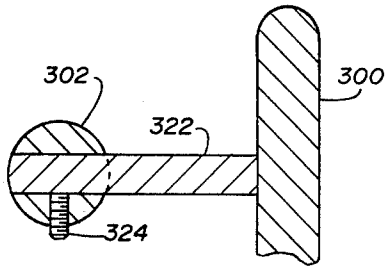


FIG. 27

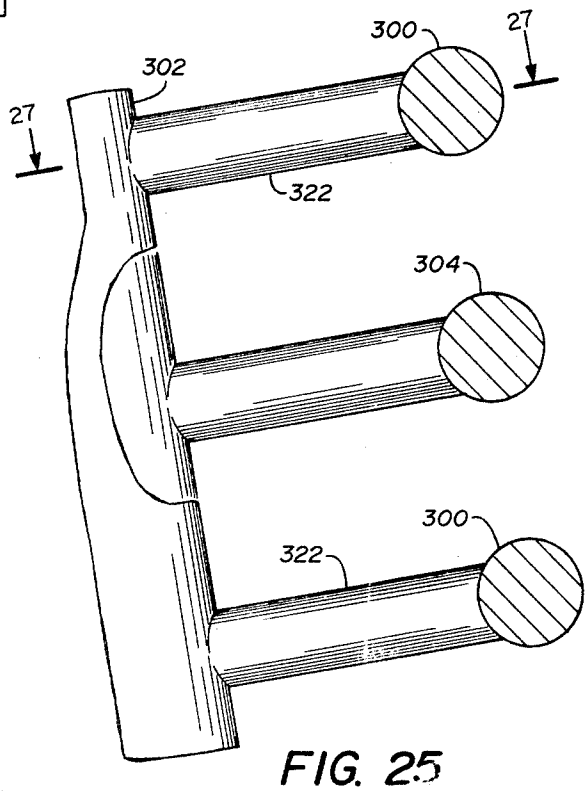


FIG. 25

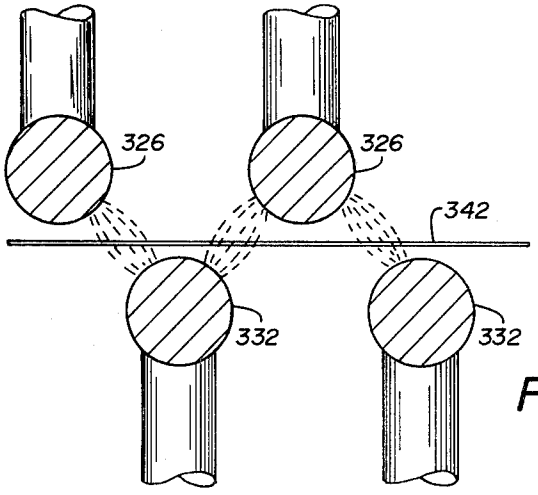


FIG. 30

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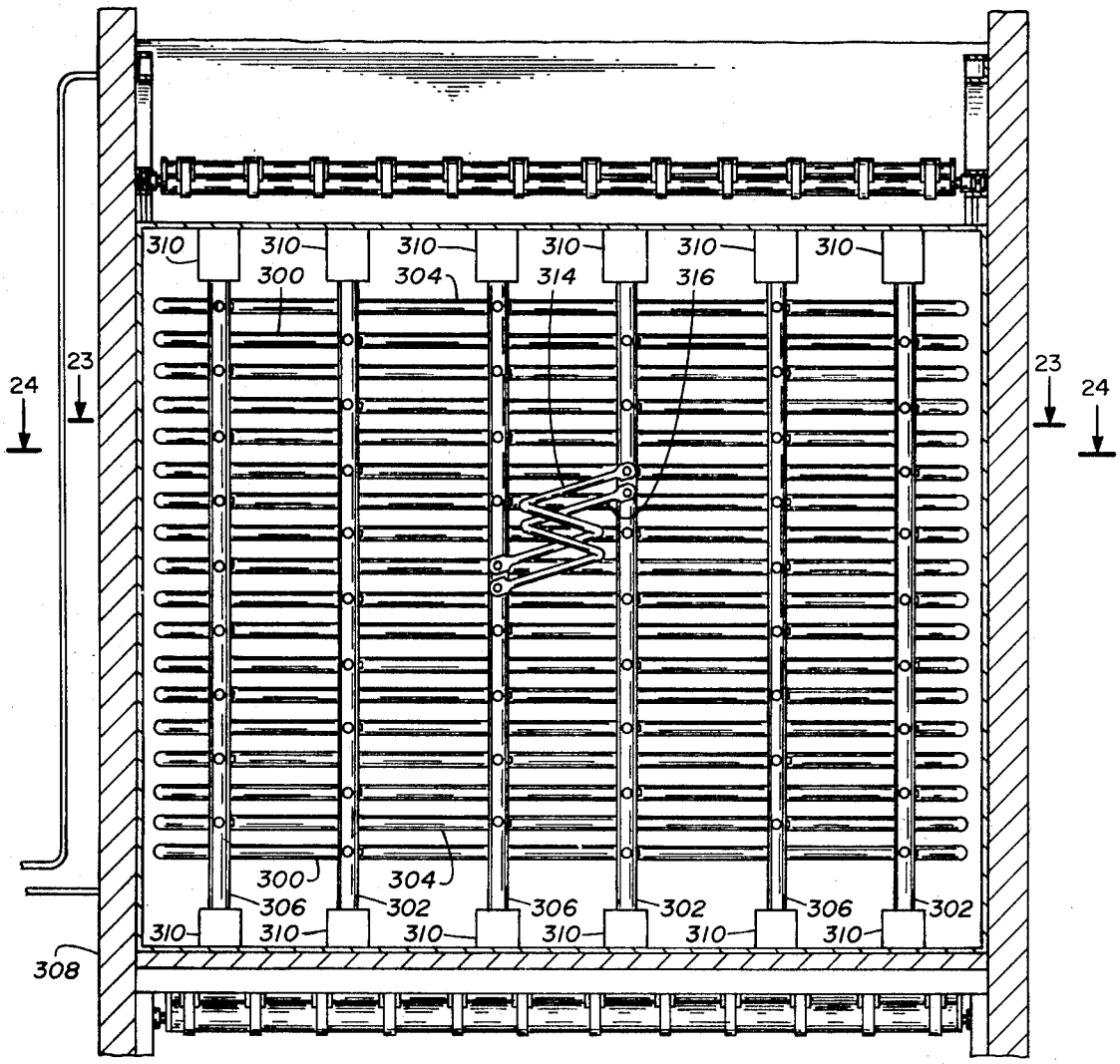

310
300
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FIG. 22

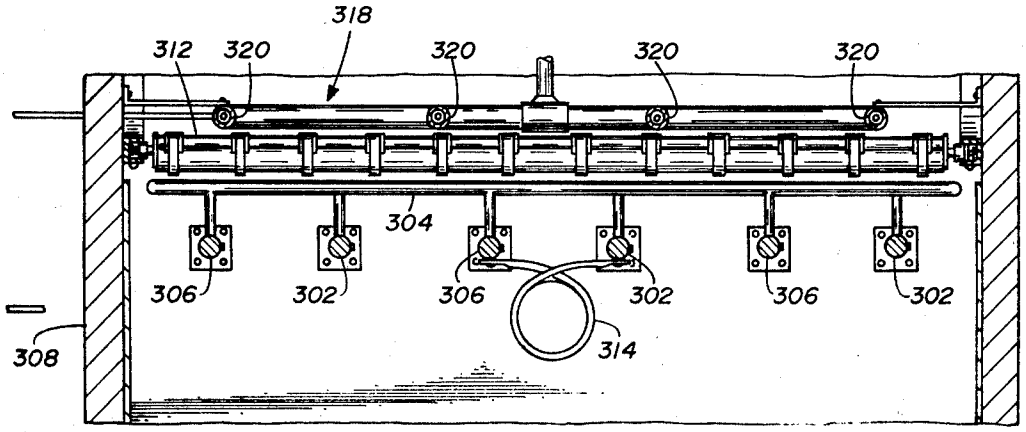

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FIG. 23

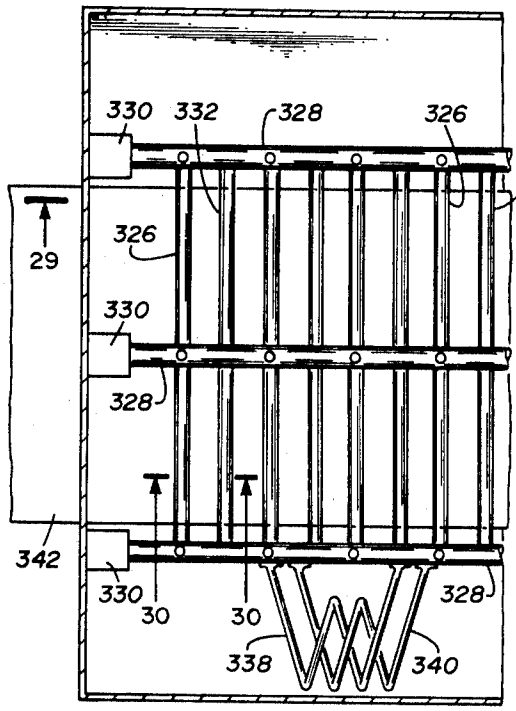


FIG. 28

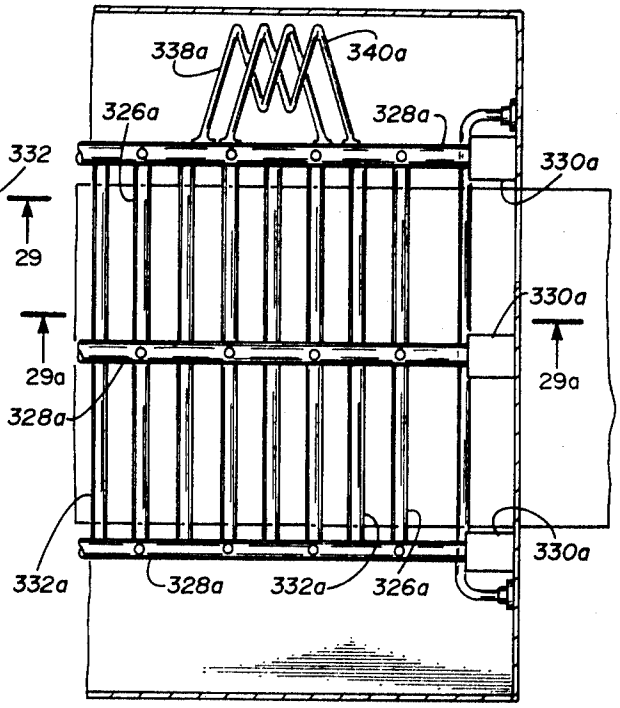


FIG. 28a

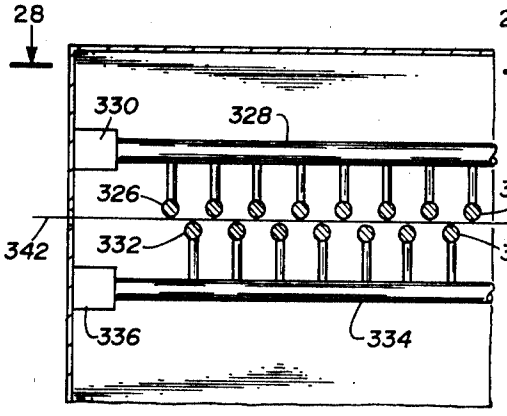


FIG. 29

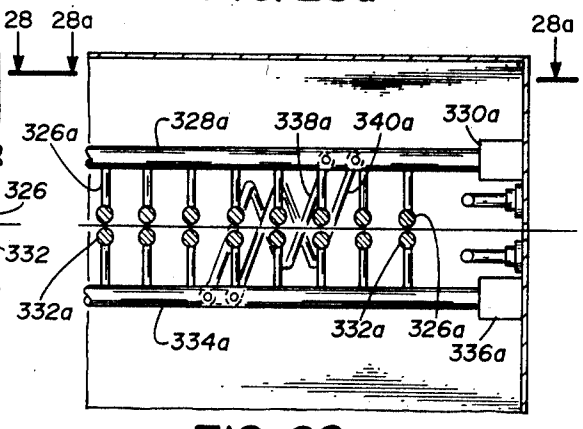


FIG. 29a

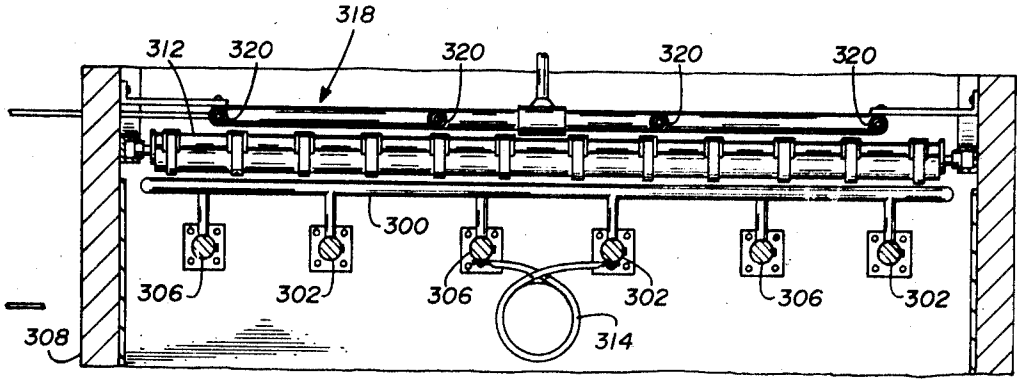


FIG. 24

METHOD AND APPARATUS FOR DRYING LIQUID DEPOSITED ON LIQUID RECEPTIVE MATERIAL

This is a continuation-in-part application of an application filed Jan. 6, 1970, Ser. No. 1,030, now abandoned.

This invention relates to electronic drying, and more particularly to electronic drying of a liquid on a liquid receptive material by a radiofrequency electromagnetic field. A major problem which has always been present in the printing industry is the offsetting or smudging of wet ink onto the back of printed sheets of paper when they are stacked in the delivery station of a printing press.

Two basic types of antioffset devices are presently being utilized by the printing industry. The most common type of antioffset device, used with sheet-fed printing presses, employs spray powder applied between individual sheets, to separate the sheets, to prevent offsetting of wet ink from the face of one sheet to the back of another sheet by holding the sheets in spaced-apart relation until the ink dries. Natural drying of the ink may require several hours, which results in wasted time before sheets can be run through the press for printing on the back of the sheets or for multicolor printing on the same side of the sheet. The spray powder is a direct result of an appreciable portion of the downtime of a printing press because powder adheres to the blanket cylinder which must be cleaned often. On long runs the powder is transferred into the ink train which must be cleaned. Powder is detrimental to the press and adjacent machinery as well as a health hazard.

Large gas-fired heating ovens are the most common type of antioffset device for use with web presses. Ovens are normally very inefficient and expensive to purchase and install and require an excessive amount of space in the printing shop. Solvents are flashed off and dissipated into the air or must be vented through elaborate systems. After paper has been run through an oven, refrigerated rollers are employed to bring the paper and ink back to room temperature. The ovens, often operating at temperatures as high as 600° F., remove an undesirable amount of moisture from the paper which makes the paper brittle, unstable and causes cracking of the paper in folding and converting operations.

Many different ink compositions have been developed in an effort to provide quick-drying ink to compensate for these problems. Varnishes, pigments, solvents, waxes, dyes and driers constitute the major elements of the various compositions of ink. Drying is accomplished primarily by the absorption of the solvents into the paper and the addition of dryers to the ink.

Heretofore attempts have been made to employ high-frequency electrical power to dry ink. However, no electronic dryer heretofore developed has had the capability of generating a useable electric field at a sufficiently high potential, and at optimum frequency, to effectively and economically dry ink in the time limits required in press operations. The long felt but unsolved need for efficient and economical drying apparatus has resulted in excessive printing costs for less than optimum quality.

This invention relates to an electronic dryer which has the capability of drying ink on a printed sheet or web. A high potential radiofrequency field, through which the paper is passed, causes slight dielectric heating of the paper. However, the temperature of the paper is not raised appreciably as it is passed adjacent the dryer and the moisture content of the paper is only slightly reduced.

It is believed that the outermost electrons of certain elements in molecules comprising the ink composition, while having high energy, are loosely bound to their nucleus and perhaps are being shared by other molecules because of their distance from the nucleus and also because of the shielding effect of the innermost electrons. As wet ink is moved through high energy electromagnetic radiation, molecular redistribution of the components of the ink results. Detachment of some of the outermost electrons in the molecules comprising the ink is thought to result in a certain amount of electromagnetically induced ionization. This is believed to cause a molecular rearrangement producing molecular attachments of very high viscosity thereby "setting" the ink very quickly.

It should be appreciated that, while the detailed description of the preferred embodiment of the invention relates primarily to the drying of ink on paper, the invention has applications for treating materials other than paper and effectively acts upon liquids other than ink.

The term "liquid receptive" as used herein means having an affinity for liquid such that liquid is attracted to the receptive material which causes atoms of the liquid to enter into or remain on the surface of the material. The term dry as used herein includes, not only, reduction in moisture, but also, changing from a soft wet state to a relatively solid state by subjecting liquid to electromagnetic energy to form a new internal molecular structure causing the liquid to set or cure. The drying apparatus described herein may be positioned at locations other than at the delivery station of a press. For example, positioning the dryer between printing stations in a multicolor press allows dry trapping wherein one color of ink is printed over another color.

The invention comprises spaced electrodes for producing a shaped, high potential field of radiofrequency electricity. The shape of the electrodes and the spacing therebetween controls the shape of the field.

A shield of dielectric material having a low dissipation factor and high breakdown voltage, such as Teflon (tetrafluoroethylene polymer,) or silicone rubber, is shaped and positioned to prevent ionization of the air in sufficient magnitude to form a conductive path, thus preventing arcing between the electrodes.

A static eliminator is incorporated into the device for removing static electric charges from the material being dried, which result from a number of contacts with dissimilar objects while moving through the press during the printing operation. The static charge is removed by passing the material through an alternating electromagnetic field, leaving the material substantially static charge free. This prevents subsequent arcing between the high potential electrodes and the material.

An object of the present invention is to provide a method and means of quickly drying ink while occupying a minimum amount of space, and without undesirable side effects, which result in downtime of the printing press, in high maintenance costs, substantial reduction in the moisture content of the paper, and reduction of printing quality.

A further object of the invention is to provide a drying device of simple inexpensive construction capable of producing a high potential electromagnetic field positioned so that paper may be moved therethrough without arcing between electrodes.

A further object of the invention is to provide a drying device of simple inexpensive construction capable of producing a high potential electromagnetic field positioned so that paper may be moved therethrough without arcing between electrodes.

A further object of the invention is to provide an electronic drying device having a static eliminator for removing static electricity from paper as it is passed adjacent thereto.

A still further object of the invention is to provide an electronic drying device which may be readily adapted to sheet-fed or web-fed lithographic printing presses.

A still further object of the invention is to provide an electronic drying device which produces a high potential radiofrequency electromagnetic field providing high efficiency for drying ink with minimum input power.

A still further object of the invention is to provide an electronic drying device generating an electromagnetic field which is designed to prevent propogation of radio waves outside of the unit.

A still further object of the invention is to provide a method of drying ink comprising the elimination of static charges, and shaping and concentrating electromagnetic energy to efficiently operate primarily on the ink.

Other and further objects of the invention will become apparent from the following description and drawings annexed hereto.

Drawings of suitable embodiments of the invention are annexed hereto so that the invention may be better and more fully understood, in which:

FIG. 1 is a side elevational view of the delivery station of a sheet-fed printing press with the dryer embodying the present invention mounted therein;

FIG. 2 is a cross-sectional view taken substantially along line 2—2 of FIG. 1 and FIG. 3;

FIG. 3 is a cross-sectional view taken along line 3—3 of FIG. 2;

FIG. 4 is a cross-sectional view taken along line 4—4 of FIG. 2;

FIG. 5 is a cross-sectional view taken along line 5—5 of FIG. 2;

FIG. 6 is a cross-sectional view taken along line 6—6 of FIG. 3;

FIG. 7 is a cross-sectional view taken along line 7—7 of FIG. 3;

FIG. 8 is a schematic wiring diagram of the electrical circuit;

FIG. 9 is an enlarged cross-sectional view taken along line 9—9 of FIG. 6;

FIG. 10 is an enlarged cross-sectional view of an electrode;

FIG. 11 is a fragmentary perspective view of an end portion and mounting of an electrode;

FIG. 12 is a fragmentary cross-sectional view taken along line 12—12 of FIG. 9;

FIG. 13 is a cross-sectional view of a second embodiment of the dryer taken along line 13—13 of FIG. 14;

FIG. 14 is a cross-sectional view taken along line 14—14 of FIG. 13;

FIG. 15 is a cross-sectional view taken along line 15—15 of FIG. 14;

FIG. 16 is an enlarged cross-sectional view taken along line 16—16 of FIG. 13;

FIG. 17 is a schematic view of a modified form of the invention;

FIG. 18 is a cross-sectional view taken along line 18—18 of FIG. 17;

FIG. 19 is a schematic view of another modified form of the invention;

FIG. 20 is a schematic view of another modified form of the invention;

FIG. 21 is a fragmentary schematic view of another modified form of the invention;

FIG. 22 is a sectional view showing the rear of an antenna employing circular radiating electrodes;

FIG. 23 is a cross-sectional view taken along the line 23—23 of FIG. 22;

FIG. 24 is a cross-sectional view taken along the line 24—24 of FIG. 22;

FIG. 25 is an enlarged cross-sectional view of three electrodes of the antenna of FIG. 22;

FIG. 26 is a fragmentary perspective view of an end portion and mounting of a circular electrode;

FIG. 27 is a fragmentary cross-sectional view taken along line 27—27 of FIG. 25;

FIG. 28 is a section of a portion of an electronic dryer taken along the line 28—28 of FIG. 29 where the liquid receptive material passes between opposing set of electrodes;

FIG. 28*a* is a sectional view taken along the line 28*a*—28*a* of FIG. 29*a* showing a modification of the antenna of FIG. 28;

FIG. 29 is a sectional view taken along the line 29—29 of FIG. 28;

FIG. 29*a* is a sectional view taken along the line 29*a*—29*a* of FIG. 28; and

FIG. 30 is an enlarged cross-sectional view of a portion of the antenna of FIG. 29.

Numeral references are employed to designate like parts throughout the various figures of the drawing.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to FIGS. 1 and 2 of the drawing, the numeral 1 generally designates a housing which contains the component parts of the oscillator section of a dryer including a radiating head or antenna 2 which comprises means for producing a shaped high-frequency, high potential electromagnetic field. Wet, liquid-receptive material, such as printed sheets of paper 4, are moved through the delivery station 12 by gripper bars 6, which are carried by an endless chain 8 on chain rails 10, mounted on the delivery station 12. Sheets 4 are transferred to the delivery station and deposited in a stack 16 after passing through one or more printing stations 14.

Chain rails 10 are grounded by a suitable conductor of high-frequency electricity 3*a* and the rails 10 are preferably constructed of a highly conductive material, such as brass, to maintain gripper bars 6 at substantially ground potential.

Electrical power, regulated through control station 22, is delivered to the inside of housing 1 through a conductor 18 connected to a conventional direct current power supply 20. Conductor 24 interconnects a conventional source of alternating current (not shown) and power supply 20. A suitable cooling system 26 may be used in conjunction with direct current power supply 20 and oscillator section 1 if it is deemed necessary to do so. An arc suppressor 21 (FIG. 8) is associated with the control station 22 as will be hereinafter more fully explained.

Control station 22 (FIG. 8) comprises suitable electrical components for adjusting the output of power supply 20. Station 22 has start and stop switches 22*a* and 22*b*, plate voltage indicator 22*c*, plate current indicator 22*d*, grid current indicator 22*e*, and control 22*f* connected to a potentiometer for regulating the output power of supply 20. Electrical conduit 22*h* contains suitable conductors for connecting control station 22 to the power supply 20.

As best illustrated in FIGS. 3, 4 and 8, an electronic tube, such as triode 30, is mounted in an oscillator circuit 32 enclosed in housing 1. Triode 30 is a conventional electrical component well known to those having ordinary skill in the art. Suitable means, such as blower 30*a*, is provided for cooling triode 30.

The cathode or filament 30*c* of triode tube 30 is connected through conductors 31 and 33 to a transformer 34 which is connected through conductors 36 and 37 to power supply (not shown).

Plate terminal 30*p* of triode 30 is connected through conductor 38 to a variable capacitor 39 in series with a variable inductance 42 which is connected through conductor 40 to mounting bar 42 as will be hereinafter more fully explained.

The grid terminal 30*g* of triode 30 is connected through conductor 44 to variable capacitor 46 which in turn is connected through conductor 47 to coil 48. Coil 48 is connected through conductor 50 to conductor 38 at node 37, to capacitor 39 and conductor 40 to mounting bar 42.

The triode 30 and the interconnection to the capacitor 46 and the coil 48 comprise an oscillator circuit. This circuit oscillates at a frequency determined by the capacitor 46 and the coil 48 and may be adjusted by means of the capacitor. In operation with the antenna 2, the oscillator continues to operate at the predetermined frequency, since the antenna does not appreciably load the circuit. To minimize the load effect by the antenna, the capacitor 39 and the inductor 42 are adjusted for the material being passed through the electromagnetic field of the antenna.

It should be noted that conductors 38, 40, 44, 47, and 50 are very short to minimize losses in the electrical circuit.

The remote control station 22 comprises a circuit for controlling the current and voltage to the oscillator circuit 32. Since this is considered to be a conventional circuit, further discussion thereof is not deemed necessary.

A conventional arc suppressor 21 is electrically connected to the oscillator circuit 32 to anticipate and prevent arcing between electrodes 56 and 58. The arc suppressor is a means

to detect an increase in the power consumed at the antenna **2** of the dryer. As an arc begins to form between electrodes **56** and **58**, the suppressor **21** detects the formation of the arc and momentarily interrupts the power supplied to the oscillator circuit. The function of the arc suppressor is to prevent damage to the material being dried and to the electrodes.

In the embodiment of the invention illustrated in FIGS. **1–12**, mounting bars **42** and **52**, **42***a* and **52***a*, and **42***b* and **52***b* have upper and lower ends attached through standoff insulators **54** to the top **1***a* and the bottom **1***b* of housing **1**. These mounting bars are disposed in spaced-apart relation with the mounting bars **42**, **42***a* and **42***b* connected to support electrodes **56** (see FIG. **4**) while mounting bars **52**, **52***a* and **52***b* are connected to and support electrodes **58** (see FIG. **5**). A plurality of electrodes **56** is provided with electrodes **58** being disposed therebetween in spaced-apart parallel relation thereto.

Tank coils **60***a* and **60***b* are connected across mounting bars **42***a* and **52***a* and tank coils **60***c* and **60***d*, across mounting bars **42***b* and **52***b*. These coils **60***a* and **60***b* are axially aligned and magnetically coupled such that mutual inductance of each is additive. Two coils **60***a* and **60***b* are employed in parallel to provide low inductance at high voltage.

Mounting bars **52**, **52***a* and **52***b*, and consequently electrodes **58**, are grounded at 53*g* through a conductor **53***a* and choke coil **53**.

While mounting bars **42** and **52** are illustrated as being substantially straight conductive members, it should be appreciated that they may be curved such that electrodes **56** and **58** would not lie in a common plane.

From the foregoing it will be apparent that electrodes **56** and **58** constitute a capacitive element in the oscillator circuit **32** while tank coils **60***a*, **60***b*, **60***c* and **60***d* constitute inductive elements. The discharge of the capacitive electrodes **56** and **58** through the inductive tank coils **60***a*, **60***b* **60***c* and **60***d* is oscillatory. As explained, since the plate terminal **30***p* of the triode **30** is connected through capacitor **46** and the coil **48** to the grid terminal **30***g*, the circuit is a free-running oscillator. The configuration of the electrodes (hereinafter more fully described), the positioning of mounting bars and the particular manner of mounting the tuning coils all contribute to the provision of an extremely efficient head **2** and the Q or energy-storing effectiveness of the oscillator circuit **32** is quite high for an electronic drying apparatus. The Q of a circuit as illustrated herein ranges from about 700 to over 1,000. Since Q is an amplification factor in such a circuit, the high voltage rise at resonance increases the drying efficiency of the head **2**.

The electromagnetic fields between electrodes **56** and **58** provide energy for drying ink on the sheet or web of paper or other suitable material **4** as the material moves through the fields. Therefore, in one embodiment of the invention, the shape and intensity of the electromagnetic field is controlled, as will be explained.

The electric charge on a conductor is distributed over the surface of the conductor and the magnetic field around a cylindrical current bearing wire is symmetrical about the wire with the strongest part of the field being near the wire. The electromagnetic field between cylindrical conductors is strongest at points along a line extending between the centers of the conductors. To efficiently cause the field to operate upon ink on a sheet or web, the material should be moved through the strongest part of the field.

Provision of an outwardly projecting surface on a conductor results in a concentration of the electric charge on the curved surface with a corresponding reduction in charge on the surfaces which are not sharply curved. Concentration of charge may rise to an extremely high value if the point is sufficiently sharp.

To this end, electrodes **56** and **58** are somewhat crescent shaped to concentrate and direct the field outwardly between adjacent bars to allow maximum utilization of the strength of the field without moving gripper bars **6** between electrodes. FIG. **9** illustrates a pair of conductors **56** and **58** mounted in spaced-apart relation.

Surfaces **57***e* and **57***f* (FIG. **10**) are preferably symmetrical about axes A and A′ which intersect at an angle B which is less than 180°. The outwardly converging convex surfaces **57***e* and **57***f* cause electrical charge to move in symmetrically converging paths to the sharply curved points **57′**. The concave front surface **56″** extends between and connects the radiating surfaces **57***f*.

Points **57′** on the edges of substantially crescent-shaped conductor **56** and points **59** on electrode **58** have a radius of curvature r_1, for example, of approximately 0.031 inches while the radius r_2 of the convex back portion **56′** and **58′** of the respective electrodes has a radius of approximately 0.21 inches. It should be noted that points **57′** have surfaces which are more sharply curved than any other surfaces on the electrode **56**. Separation between the centers of the bars varies with the strength of the applied field. It should be understood that the dimensions are merely illustrative and not intended to be limiting in nature. However, the specific ratio of r_1:r_2 provides good concentration of charge along points **57** and **59** and the symmetrical configuration and inclination of points **57** and **59** is very efficient for directing the fields in a controlled direction.

It should thus be readily apparent that the crescent-shaped electrodes **56** and **58** will direct the electromagnetic field outwardly allowing the sheet **4** to be moved therethrough.

At high potentials, the air surrounding a conductor becomes partially ionized, resulting in brush or "corona discharge" which represents a leakage of energy. The "corona discharge" occurs when the potential gradient exceeds a certain value but is not sufficient to cause arcing.

As best illustrated in FIGS. **4**, **5**, **11** and **12**, opposite ends of electrodes **56** and **58** are bent or deflected to form loops **56***a* and **56***b* and **58***a* and **58***b* with the inner ends of the the respective loops being secured to mounting bars **42***a*, **42***b*, **52***a* and **52***b*, respectively, and coils **60***a*, **60***b*, **60***c*, and **60***d* are mounted as hereinbefore described to minimize voltage built up on the ends of the electrodes. Loops in the end of electrodes **56** and **58** reduce the energy which is radiated from the ends of the bars to minimize corona discharge and prevent arcing between the ends of the electrodes and between the electrodes and the sides of housing **1**.

Referring to FIGS. **4**, **5** and **11**, it should be noted that each electrode **56** comprises a straight elongated conductive element **56***d* which has a curved, substantially U-shaped end portion **56***a* on one end thereof and a curved end portion **56***b* on the other end. Points or projections **57** constitute elongated conductive surfaces on the electrode **56** to shape or direct the electromagnetic field between adjacent electrodes.

The substantially crescent-shaped cross section of the straight portion of each electrode feathers out at the ends, as illustrated at **56***c* (FIG. **11**), such that the curved end portions **56***a* and **56***b* are substantially circular in cross section. Therefore, the end sections **56***a* and **56***b* are of circular cross section to minimize the concentration of surface charge and curved in a substantially horizontal plane to minimize corona discharge at the ends of the electrodes.

The inner ends of curved portions **56***a* and **56***b* are connected to straight portions **56***e* and **56***f*, respectively, which extend inwardly in substantially parallel spaced-apart relation to sections **56***d*. Portions **56***e* and **56***f* join through curved segment **56***g* with outwardly directed terminal **56***h* which is adapted to be connected through mounting bars **42** to the oscillator **32**.

Mounting bars **42**, **42***a*, **42***b*, **52**, **52***a* and **52***b* have sockets formed therein to receive outwardly directed terminals **56***h*, **58***h*, respectively. The terminals on the electrodes are secured in the sockets by setscrews **56***j* and **58***j*, as best illustrated in FIG. **12**.

Electrodes **56** are secured to mounting bar **42** by feed terminals **56***t* which extend outwardly from a portion of each electrode **56** intermediate the curved end portions **56***a* and **56***b* thereof. Electrodes **58** are secured to mounting bar **52** by feed terminals **58***t*.

Positioning terminals **56***t* and **58***t* intermediate opposite ends of the electrodes provides more uniform loading over the area adjacent the antenna **2** thereby resulting in a more balanced electromagnetic field across the antenna at high frequencies than would be achieved if feed terminals were on the ends of the electrodes.

Electrodes **56** and **58** are of substantially identical construction. Referring to FIGS. **4** and **5**, it should be apparent that portion **56***e* of each electrode **56** is shorter than portion **56***f* on the other end of the electrode while portion **58***f* of each electrode **58** is shorter than portion **58***e*. This allows spacing of mounting bars without providing electrodes of several different forms and dimensions.

The inner ends of the loops in electrodes **56** terminate adjacent mounting bars **42***a* and **52***b*.

The inner ends of loops **58***a* and **58***b* are terminated adjacent to mounting bars **52***a* and **52***b*.

To keep electrical losses low, electrodes **56** and **58** and the feeder system must have good conductivity and the insulators **54** must have low dielectric loss and low surface leakage. The electrodes may be constructed of copper, aluminum, stainless steel, or other well-known electric conductive materials.

As hereinbefore pointed out, the loss in a given length of transmission line rises with increase in frequency. Therefore, feedlines between triode **30** and mounting bar **42** should be kept as short as possible.

The crescent-shaped electrodes may be constructed with sufficient cross-sectional area to provide rigidity for the electrodes, thereby minimizing deflection along the length thereof. This further assures uniformity of the field along the length of the electrodes.

Air is usually a nonconductor of electricity. Its molecules are complete in themselves, and neutral, taking no observable part in electric actions so long as they remain neutral.

When an air molecule is exposed to a high potential electromagnetic field, conditions are created in which disturbances occur of sufficient violence to remove an occasional electron from one of the molecules. When this happens the electron usually attaches itself to a neutral molecule, thus making it into a negatively charged particle or a negative ion. The molecule which released the electron becomes a positive ion. Ions are thus charged molecules carrying with them a quantity of negative or positive charge which does not balance the charges of their nuclei.

A great number of ionized molecules can thus be created with the result that the air becomes a conductor and neutralizes the charges which were creating the electric field.

An electric arc results from the sudden breakdown of the insulating strength of the air or other dielectric material separating two electrodes, due to the formation of ions by the intense electric field, accompanied by a rush of electricity through the ionized molecules. The arcing potential between charged bodies is a substantially linear function of the distance between the charged bodies, and for a given distance the arcing potential is a substantially linear function of the potential.

The use of crescent-shaped electrodes **56** and **58** for directing and concentrating the electromagnetic field between the spaced electrodes sets up a voltage along points **57** and **59**, respectively, which may exceed the arcing potential of static air insulation therebetween. The substitution of other insulating materials for air increases the potential gradient which may be held between points **57** and **59** on the spaced electrodes.

The ratio of the capacitance with some material other than air between the plates of a capacitor, to the capacitance of the same capacitor with air insulation, is called the dielectric constant of that particular insulating material. When a high voltage is applied to conductors separated by a dielectric, a considerable force is exerted upon the electrons and nuclei of the dielectric. Since the dielectric is an insulator and the electrons do not become detached from their atoms, if the force is great enough the dielectric will "break down," resulting in a puncture of the dielectric material which will char and permit current to flow. The breakdown voltage depends upon the composition and thickness of the dielectric material employed.

When conductors on opposite sides of a sheet of dielectric material are oppositely charged a mechanical strain is exerted upon the atoms of the dielectric material. The positively charged particles of the atoms are pulled toward the negatively charged conductor while the negative parts are pulled toward the positively charged conductor. During the extremely short time that the atoms of the dielectric material are being realigned or polarized, there is an apparent current flow of electricity due to the displacement of the charged particles, which is referred to as the displacement current. If the electric field is reversed, the displacement current occurs for an instant in the opposite direction.

The reorientation of molecules results in heating of the dielectric material by molecular friction, the heat being dissipated to the air adjacent thereto. The power loss due to the dielectric heating is the dielectric loss of the material.

Four primary criteria must be met by a dielectric to function effectively to prevent arcing between electrodes **56** and **58**. The dielectric material should have a reasonably high dielectric constant, a low dissipation factor, and a high breakdown voltage so that the material will provide good dielectric qualities over a wide range of operating frequencies and at high voltage. The dielectric material may be formable or moldable to provide a configuration similar to that illustrated in FIG. **9** of the drawing.

Since it is necessary that sheet **4**, carried by a gripper bar, be moved through the electromagnetic field, it is desirable that the electrodes **56** and **58** be positioned on the same side of the sheet to allow the gripper bar to pass adjacent thereto. As hereinbefore pointed out, it is desirable that the field between the electrodes be deflected outwardly to facilitate moving the sheet therethrough and the dielectric material must extend across the field between the electrodes without interfering with the movement of the sheet **4** through the field.

Experiments reveal that positioning a flat sheet of dielectric material across points **57** and **59** of electrodes **56** and **58**, respectively, while it does increase the voltage differential which can be held between the electrodes without arcing, additional benefit can be obtained by using a shaped dielectric sheet. The flat sheet, alone, allows the formation of ionized air, which becomes a conductor, allowing an arc to form between the electrodes.

As best illustrated in FIG. **9** of the drawings, shield **70** in a preferred form comprises a sheet of dielectric material having portions draped and extending between electrodes **56** and **58** forming a series of troughs **72** which are connected by portions **76** and **78** which extend across points **57** of electrode **56** and across points **59** of electrode **58**, respectively. Provision of trough portion **72** between electrodes **56** and **58** increases the distance which ionized air must travel to form an arc, by directing the ions rearwardly around the trough portion **72**. It should be noted that shield **70** extends across the electromagnetic field without interference with the movement of sheet **4** through the field and controls the distance and direction of travel of the ionized air before it is electrically connected to an oppositely charged substance.

Selection of a material fro construction of sheet **70**, which has a low dissipation factor, is important to minimize dielectric heating of the material with resultant changes in molecular structure, and in some instances melting of the material. Use of material having a low dissipation factor also minimizes ionization of air from the displacement current in the dielectric material, thereby eliminating arcing and minimizing corona discharge.

Various materials may be employed for constructing shield **70**. Teflon, a tetrafluoroethylene polymer, has outstanding chemical resistance, excellent electrical properties and good heat stability. Teflon is a thermoplastic which may be readily machined or formed and has a dielectric constant of approximately 2.1, a dissipation factor of less than 0.0002 at one megacycle and a puncture voltage of between 1,000 and 2,000

volts per mil (0.001 inch). Teflon is a noncombustible material and has no true melting point. However, it undergoes a solid-phase transition to a gel at 325° C. with a sharp decrease in strength; and at 400° C. it decomposes slowly to a gaseous monomer and some gaseous, fluoride derivatives.

Shield **70** may be constructed of materials other than Teflon which have a low dissipation factor, high puncture voltage and good formability. One such material is silicone rubber having a dielectric constant of approximately 3.1 and a dissipation factor of 0.0009 at one megacycle. Silicone rubber retains its elasticity at temperatures as high as 300° C. and is unaffected by ozone and corona. Silicone rubber is self-healing since it does not char if arcing occurs. However, silicone rubber is inferior to Teflon in one respect in that since it has a higher dissipation factor the dielectric heating of a silicone rubber shield results in power loss, reducing the efficiency of the dryer.

Housing **1** in which the oscillator circuit and the head **2** are mounted is constructed of brass, copper, aluminum or other materials which are good conductors of radiofrequency electricity. The region occupied by head **2** is completely enclosed by metal, forming an enclosure which is opaque to electromagnetic radiation, thus minimizing the propagation of radio waves into the atmosphere surrounding the housing **1**.

Housing **1** is maintained at ground potential by connecting said housing through a conductor **3** connected to ground. Delivery station **12** of the printing press is also maintained at ground potential through grounded conductor **3**. Metallic plate **12***a* of delivery station **12** extends transversely across the front of head **2** in spaced-apart relation therefrom and acts as a front for housing **1**. Side frames **12***b* and **12***c* of delivery station **12** extend across the ends of electrodes **56** and **58** in spaced-apart relation therefrom and close the ends of the space between plate **12***a* and the open front of housing **1**. The edges **70***e* of shield **70** are secured to the housing **1** and are curved to wrap around the ends **56***a* and **56***b* of the electrodes as best illustrated in FIG. **4**. The upper and lower edges **70***f* of the shield are secured to the top and bottom of the housing **1** as illustrated in FIG. **3**.

Housing **1** has openings **1***e*, if in opposite ends thereof for circulation of air through the housing to cool tube **30**. Screens **1***s* are disposed across the openings **1***e* and **1***f* to prevent the propagation of electromagnetic waves therethrough.

As best illustrated in FIGS. **3**, **4**, **6** and **7**, means comprising a blower manifold **80** is provided for urging and holding the printed sheet **4** in the radiated field. Manifold **80** comprises vertically disposed spaced hollow tubular members **82** connected by horizontally disposed spaced hollow tubular members **84** and **85**. A suitable source of pressurized air, such as blower **86**, is connected to conduit **88** and a suitable coupling **89** to the inside of the hollow tubular members. Passages **90** extend through the walls of tubular members **82**, **84** and **85** such that compressed air passing through conduit **88** into the hollow portion of the tubular members is directed through passages **90** onto the surface of sheet **4**, thereby urging the sheet toward electrodes **56** and **58** to maintain the sheet in the outwardly directed field between the electrodes. Manifold **80** is held in position by supports **92** secured to the side frames of the delivery station.

As the sheet **4** is moved through the printing press, static electricity is generated in the sheet. The amount of charge and the polarity of the charge depends upon many variables such as the type of paper, the type of ink, press speed, humidity and temperature. If sheet **4** carries a high static charge, as it is moved adjacent electrodes **56** and **58**, arcing will result from the sheet to the electrodes, causing severe damage to the sheet making it unuseable.

Means is provided for removing the static charge from sheet **4** before it is moved into close proximity of electrodes **56** and **58** in head **2**.

A suitable embodiment of a static eliminator **95** is illustrated in FIGS. **7** and **8** of the drawing. Conductors **96** are electrically connected through a conductor **98** to a source of either alternating or direct current electricity such as transformer **100**. Transformer **100** is connected through conductor **98***a* to the frame of delivery station **12**, which is maintained at ground potential through conductor **3**. Conductor **96** extend through hollow portions of tubular members **82**, **84** and **85** such that air directed through passages **90** in said tubular members is slightly ionized as a result of corona and is effective to reduce the static charge in sheet **4** as it contacts the sheet.

A modified form of a static eliminator is illustrated in FIGS. **17** and **18** of the drawing. Conductors **97** and **99** may have a cross section identical to that of the electrodes **56** and **58** such that an outwardly directed electromagnetic field will exist therebetween when the electrodes are connected to conductors **98** and **98***a*, which are connected to transformer **100** as hereinbefore explained. Oppositely charged electrodes **97** and **99** produce an electric field therebetween, which is of lower frequency than that generated between electrodes **56** and **58**, to remove static charge from the sheet before the sheet is moved into the higher frequency field where drying is accomplished.

DESCRIPTION OF A SECOND EMBODIMENT

A second embodiment of the arrangement of the electrodes is illustrated in FIGS. **13–16** of the drawing.

The first embodiment of the invention hereinbefore described and illustrated in FIGS. **1–12** of the drawing may be employed with a web press for drying ink on a web **104**. However, since gripper bars are not employed for moving the web **104** through the press, electrodes **156** and **158** in the modified form may be positioned on opposite sides of the web **104**.

Electrodes **156** on one side of the web are connected to mounting bar **142** which in turn connected to the oscillator circuit through conductor **40** as hereinbefore explained with respect to the first embodiment. Electrodes **158** are positioned on the opposite side of the web **104** and are supported by mounting bar **152**, which is connected through conductor **153***a* and choke coil **153** to ground.

Dielectric shields **170***a* and **170***b* are employed to prevent ionization of the air which would result in arcing between electrodes **156** and **158**.

Tank coils **160***a* and **160***b* are connected to mounting bars **142***a* and **152***a* while tank coils **160***c* and **160***d* are connected to mounting bars **142***b* and **152***b*.

Electrodes **156** and **158** are slightly different configuration from electrodes **56** and **58**, hereinbefore described. The curved end portions **156***u* and **158***u* of electrodes **156** and **158** do not extend inwardly toward the center of each electrode to facilitate attachment of tank coils **160***a*, **160***b*, **160***c* and **160***d* to mounting bars outwardly of the edges of the web **104**.

The crescent-shaped cross section of the electrodes feather into a substantially circular cross section as shown at **156***c* and **158***c*.

A third form of a static eliminator is illustrated in FIG. **14** wherein electrodes **197** and **199** are positioned on opposite sides of the web **104** and to conductors **98** and **98***a* as hereinbefore explained.

Housing **101** extends around radiating heads **102***a* and has slots **101***s* in opposite ends thereof through which the web **104** passes.

DESCRIPTION OF A THIRD EMBODIMENT

As hereinbefore pointed out the primary function of shield **70** is to prevent completion of a circuit of ionized air which would result in arcing between electrodes **56** and **58**. Means other than a shield **70** may be employed to prevent ionization of the air in sufficient quantities to prevent arcing between the electrodes. In the embodiment of the invention illustrated in FIGS. **19** and **20** of the drawing, radiating head or antenna **202** comprises spaced electrodes **256** and **258**, positioned across the open side of housing **201**. A blower **230***a* is mounted inside the housing **201** and draws air from the inside of the housing and exhausts air through an opening in the wall thereof.

If a sufficient quantity of air is drawn between the spaced electrodes **256** and **258** arcing will not occur across the gap between the electrodes.

While air becomes ionized in the vicinity of each electrode **256** and **258**, it is immediately dispersed rearwardly toward blower **230***a*, preventing formation of an arc which would damage the sheet and electrodes.

A modified form of a third embodiment of the invention is illustrated in FIG. **20** wherein blowers **230***b* and **230***c* are disposed within housing **201'** for drawing air from between electrodes **258'** and **256'** for use upon a web **204**.

The form of the invention illustrated and described as the first and second embodiments employs shields **70**, **170***a*, **170***b* to eliminate arcing as a result of ionization of air adjacent electrodes **56** and **58** by increasing the distance which the ionized air must travel to form an arc. The third embodiment of the invention illustrated in FIGS. **19** and **20** prevents arcing by drawing ionized air from the vicinity of the electrodes by blower means.

Another modified form is illustrated in FIG. **21** wherein a shield **270** of dielectric material is positioned as hereinbefore described with relation to shields **70** and **170**.

However, shield **270** has apertures **272***h* formed therein to form passages through which air may be circulated by blower of the type designated by numeral **230***a* in FIG. **19** of the drawing.

DESCRIPTION OF A FOURTH EMBODIMENT

Referring to FIGS. **22–27**, there is illustrated an embodiment of the invention wherein the antenna radiating the radiofrequency electromagnetic field comprises electrodes having a circular cross section. Previous embodiments of the invention have illustrated the electrodes as having a generally crescent-shaped cross section. The antenna of this embodiment includes electrodes **300** supported on mounting brackets **302** interspersed with electrodes **304** supported on mounting bracket **306**. One of the mounting brackets **302** is connected to the oscillator circuit of FIG. **8** through the conductor **40** as hereinbefore explained with respect to an earlier embodiment. Mounting brackets **306** are coupled to ground through the choke coil **53**. The complete antenna structure is supported in a housing **308** through standoff insulators **310**. Wet, liquid-receptive material, such as printed sheets of paper, are moved through an electromagnetic field radiating from the antenna by gripper bars **312** in a manner as explained previously. Interconnecting the mounting brackets **302** and **306** are inductors **314** and **316**. Although the inductors are illustrated as one-turn coils, sufficient inductance may be generated to form a tank circuit with the electrodes **300** and **304** by a straight bar interconnecting the mounting brackets. Where required, the inductors **314** and **316** may be water cooled.

Where required, a static eliminator **318** is positioned from the antenna to reduce the static charge on a material transported past the radiating antenna. This static eliminator comprises conductors in tubular members **320**. A similar static eliminator has previously been described.

Referring particularly to FIGS. **25–27**, there is shown in detail the cross section of the electrodes **300** and **304** and the supports for mounting the mounting brackets. Electrodes **300** are attached to the mounting bracket **302** by standoff supports **322** secured to the mounting bracket by a setscrew **324**.

Although not specifically illustrated in FIG. **22–27**, a dielectric shield may be positioned around and between the electrodes **300** and **304** to subdue arcing between the electrodes caused by ionization of the surrounding air. Also, as explained previously, the air surrounding the electrodes **300** and **304** may be displaced by means of a blower. The blower continuously replaces the ionized air thereby minimizing the possibility of arcing between the electrodes.

FIFTH EMBODIMENT OF THE INVENTION

Referring to FIGS. **28–30**, there is shown an embodiment of the invention wherein electrodes having a circular cross section are mounted such that the liquid-receptive material passes between opposed electrode arrangements. The systems illustrated in FIGS. **28** and **28***a* both comprise this fifth embodiment with the electrodes of the system of FIG. **28** on opposite sides of the liquid-receptive material displaced as illustrated in FIG. **29**. In describing this fifth embodiment, reference numerals followed by a letter identify the system of FIG. **28***a*.

Electrodes **326** are supported on mounting brackets **328** which are in turn attached to a housing by means of standoff insulators **330**. Electrodes **326** comprise the upper half of an antenna; the lower half of the antenna includes electrodes **332**. The lower half electrodes **332** are supported on mounting brackets **334** which in turn are attached to the dryer housing through standoff insulators **336**. As best illustrated in FIG. **29**, the lower set of electrodes of the system of FIG. **28** are displaced from the upper half electrodes. The system of FIG. **28** a, as best illustrated in FIG. **29***a*, has the lower set of electrodes in line with the upper set of electrodes.

A tank circuit is formed with the upper set of electrodes **326** and the lower set of electrodes **332** by inductors **338** and **340** connected to an upper mounting bar **328** and a lower mounting bar **334**. As explained previously, the inductors **338** and **340** may be a straight bar or a bar with a slight curvature, but need not be a coil.

Referring to FIG. **30**, there is diagrammatically illustrated an electromagnetic field between the upper electrodes **326** and the lower electrodes **332** for the system of FIG. **28**. As the liquid-receptive material **342** passes through the electromagnetic field, there will take place a drying action of the liquid carried by the material.

In the embodiment of FIGS. **28–30**, the individual electrodes of the antenna may be mounted as illustrated in FIGS. **25–27**. By interconnecting the electrodes at several points along their lengths, and in addition relatively close to the end terminations, a balanced electromagnetic field will be produced. To minimize arcing between the electrodes, a blower may be employed to continuously displace and carry away the ionized air as illustrated in FIG. **20**.

While several embodiments of the invention, together with modifications thereof, have been described in detail herein and shown in the accompanying drawings, it will be evident that various other modifications are possible without departing from the scope of the invention.

What is claimed is:

1. In a system for drying a liquid on a liquid-receptive material, comprising:

an antenna positioned along the path of travel of the liquid receptive material, said antenna including a first plurality of spaced electrodes and a second plurality of spaced electrodes with individual electrodes of the second group disposed between adjacent electrodes of pairs of the first group in the spaced-apart parallel relation thereto,

inductance means connected across said first and second plurality of electrodes to form a tank circuit therewith,

generating means having a current output coupled to said antenna,

means for electrically interconnecting the spaced electrodes in groups to produce a substantially balanced electromagnetic field radiating from said antenna through the liquid receptive material, and

means for direct coupling the groups of spaced electrodes to said generating means in a free-running oscillator configuration.

2. In a system for drying a liquid on a liquid-receptive material as set forth in claim **1** including a capacitor in series with an inductance connected between said generating means and said antenna.

3. In a system for drying a liquid on a liquid-receptive material as set forth in claim 1 including means associated with said antenna to subdue arcing between the electrodes.

4. In a system for drying a liquid on a liquid-receptive material as set forth in claim 3 wherein said means to subdue arcing between electrodes includes a blower for directing ionized air away from said antenna.

5. In a system for drying a liquid on a liquid-receptive material as set forth in claim 3 wherein said means associated with said antenna for subduing arcing between electrodes comprises a dielectric shielding material surrounding the spaced electrodes.

6. In a system for drying a liquid on a liquid-receptive material as set forth in claim 1 wherein the spaced electrodes of said antenna have a circular cross section.

7. In a system for drying a liquid on a liquid-receptive material as set forth in claim 1 wherein the spaced electrodes of said antenna have a substantially crescent-shaped cross section.

8. In a system for drying a liquid on a liquid-receptive material as set forth in claim 1 including means for discharging static electric charge on the liquid-receptive material positioned along the path of travel thereof.

9. In a system for drying a liquid on a liquid-receptive material as set forth in claim 8 wherein said means associated with said antenna for subduing arcing between electrodes comprises:

a second plurality of spaced electrodes, and

generating means coupled to said electrodes producing a current output to generate an electromagnetic field through which the liquid-receptive material passes along the path of travel thereof.

10. In a system for drying a liquid on a liquid-receptive material, comprising:

a first plurality of electrodes in spaced-apart relation in an enclosing housing,

a second plurality of spaced electrodes with individual electrodes thereof disposed between adjacent electrodes of pairs of said first plurality of electrodes in spaced-apart parallel relation thereto,

inductance means connected across said first and second plurality of electrodes to form a tank circuit therewith,

generating means having a current output direct coupled to said plurality of electrodes in a free-running oscillator configuration to produce an electromagnetic field radiating therefrom to the liquid-receptive material,

dielectric shielding materials surrounding said electrodes to subdue arcing therebetween, and

means for moving the liquid-receptive material through the balanced electromagnetic field to effect a drying action of the liquid on the liquid-receptive material.

11. In a system for drying a liquid on a liquid-receptive material as set forth in claim 10 wherein said means for moving the material through the balanced electromagnetic field includes gripper bars having opposite ends thereof movable along chain rails, and

grounded conductors extended along the chain rails to maintain said gripper bars at a ground potential.

12. In a system for drying a liquid on a liquid-receptive material as set forth in claim 10 wherein the electrodes have a substantially crescent-shaped cross section.

13. In a system for drying a liquid on a liquid-receptive material as set forth in claim 10 wherein said electrodes have a substantially circular cross section.

14. In a system for drying a liquid on a liquid-receptive material as set forth in claim 10 wherein the dielectric shielding material has a low dissipation factor.

15. In a system for drying a liquid on a liquid-receptive material as set forth in claim 10 wherein the dielectric shielding material has a high breakdown voltage.

16. In a system for drying a liquid on a liquid-receptive material as set forth in claim 10 wherein the dielectric shielding material is formed sheet of tetrafluoroethylene polymer extending across the front and between the sides of the electrodes in an undulatory path to provide troughs of shielding material between adjacent electrodes.

17. In a system for drying a liquid on a liquid-receptive material as set forth in claim 10 wherein the electrodes are arranged to form first and second heads, the first head and second head being disposed on opposite sides of the liquid-receptive material.

18. In a system for drying a liquid on a liquid-receptive material as set forth in claim 10 wherein the housing supporting said electrodes is maintained at a ground potential and constructed of an electrically conducted material.

19. In a system for drying a liquid on a liquid-receptive material as set forth in claim 17 including means for urging the liquid-receptive material into sliding contact with the dielectric shielding material.

20. In a system for drying ink on a ink-receptive material as the material moves through a printing press comprising:

a first plurality of shaped electrodes spaced along and mounted to a first supporting frame,

a second plurality of electrodes spaced along and mounted to a second supporting frame, said second plurality of electrodes having individual elements thereof disposed between adjacent electrodes pairs of said first plurality of electrodes in a spaced-apart parallel relation thereto,

first mounting means for supporting the first plurality of spaced electrodes on said first supporting frame,

second mounting means for supporting the second plurality of spaced electrodes on said second supporting frame,

inductance means electrically connected between said first plurality and said second plurality of electrodes to form a tank circuit therewith,

means for electrically connecting the first supporting frame to ground, and

generating means having a current output direct coupled to the second supporting frame to form a free-running oscillator with said tank circuit and for producing an electromagnetic field radiating from said electrodes through the ink-receptive material.

21. In a system for drying ink on ink-receptive material as set forth in claim 20 including a static eliminator positioned along the path of the material to discharge static charges on the ink-receptive material prior to the material moving through the electromagnetic field produced by said first and second plurality of electrodes.

22. In a system for drying ink on an ink-receptive material as set forth in claim 20 including means associated with the electrodes to prevent ionization of air between electrodes of sufficient magnitude to cause arcing therebetween.

23. In a system for drying ink on a ink-receptive material as set forth in claim 22 wherein said means associated with said electrodes to prevent ionization of air includes;:

a housing extending around the electrodes opposite the path of the moving material, and

a blower arranged to direct air through said housing such that ionization of air adjacent said electrodes is minimized to prevent arcing.

24. In a system for drying ink on an ink-receptive material as set forth in claim 20 wherein said electrodes have a substantially crescent-shaped cross section.

25. In a system for drying ink on an ink-receptive material as set forth in claim 24 wherein the said substantially crescent-shaped cross section of the electrodes feathers into a substantially circular cross section at opposite ends of each electrode.

26. In a system for drying ink on an ink-receptive material as set forth in claim 20 including means mounted in spaced-apart relation from the electrodes for directing the ink-receptive material into the balanced electromagnetic field.

27. In a system for drying ink on an ink-receptive material as set forth in claim 26 wherein the means for directing material into the balanced electromagnetic field is a perforated manifold, and

a source of pressurized air communicating with the manifold to direct air through the perforation against the material.

28. In a system for drying ink on an ink-receptive material as set forth in claim **20** wherein the electrodes of said first and second plurality are arranged to form first and second heads, the first head and second head being disposed on opposite sides of the ink-receptive material.

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