

TITLE: METHOD AND APPARATUS FOR DELIVERING ELECTROMAGNETIC
ENERGY INTO A SOLUTION

BACKGROUND OF THE INVENTION

5 The present invention relates to a method and
apparatus for delivering electromagnetic energy into a colloidal
suspension, i.e., a solution, for the purpose of modifying its
characteristics.

 Various systems are known for treating water or
10 other solutions by introducing electric or magnetic energy. For
example only, see U.S. Patents 4,865,747; 4,865,748; 4,963,268;
5,036,170; 5,074,998; 5,113,751; 5,139,675; 5,171,431;
5,173,169; 5,183,512; 5,183,565; 5,217,607; 5,230,807;
5,236,670; 5,304,289; 5,306,887; 5,320,726; and 5,326,446.

15 Further, it has been reported in a paper by Zeta-
Meter, Inc., a manufacturer of equipment for monitoring zeta
potential, that "Zeta potential can help you understand and
control colloidal suspensions. Examples include complex
biological systems such as blood and functional ones like paint.
20 Colloidal suspensions can be as thick as paste (like cement) or
as dilute as the turbidity particles in a lake. Water, milk,
wine, clay, dyes, inks, paper and pharmaceuticals are good
examples of useful colloidal systems. Water is a common
suspending liquid, although non-aqueous liquids are used as
25 well. In many cases, the performance of a suspension can be
improved by understanding the effect of colloidal behavior on
such properties as viscosity, settling and effective particle
size." See: "Zeta Potential: A Complete Course in 5 Minutes"
which is incorporated herein by reference.

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SUMMARY OF THE INVENTION

The present invention is directed to an apparatus for the delivery of RF-modulated electromagnetic energy, i.e., magnetic and electric fields, into a solution for modifying the characteristics of the solution. Furthermore, the present invention is directed to a method and apparatus for modifying the characteristics of a second solution by delivering RF-modulated electromagnetic energy, i.e., magnetic and electric fields, into a first solution and then causing the first solution to be proximate to said second solution.

Preferred embodiments of delivery apparatus in accordance with the invention are comprised of 1) a tubular housing having closed ends and forming a water-tight chamber, 2) a coil contained within the chamber delivering a magnetic field into a solution, 3) at least one electric field probe coupled to the coil for delivering an electric field into the solution, and 4) coupling means for coupling an electromagnetic signal to the coil.

In a preferred embodiment, the electric field probe (hereinafter, the "voltage" probe) is contained within a chamber containing a first solution electrically isolated from a second solution which one desires to treat. A signal generator coupled to the coil is used to energize the delivery apparatus for producing the magnetic and electric fields. The signal generator is preferably configured to adjust the amplitude and duty cycle of the energizing signal.

A delivery apparatus in accordance with the invention, is typically used in proximity to a solution whose characteristics, as indicated by its zeta potential or any other appropriate measure of the modified characteristics of the solution, can be modified by applied RF-modulated energy. In accordance with one aspect of the invention, the applied RF energy is controlled, i.e., power level, duration and duty cycle to optimize solution treatment. Moreover, the distribution of delivery apparatus units within the solution is also selected to optimize solution treatment.

A preferred method for treating a second solution, comprises the steps of: 1) applying RF-modulated energy to a



first solution, and 2) causing said first solution to be proximate to a second solution to treat said second solution.

In a further aspect of a preferred method, the first solution is transported between a treatment station, where
5 the RF-modulated energy is applied to the first solution, to a process station which contains the second solution. At the process station, the first solution is then passed proximate to the second solution to treat the second solution.

A delivery apparatus in accordance with the
10 invention, preferably practices the preferred method by recirculating the first solution within a closed pipe isolated from the second solution.

In an alternative preferred method for treating a solution, the second solution is transported from a process
15 station to a treatment station which contains the first solution which has been treated with the RF-modulated energy. After passing the second solution proximate to the first solution, the second solution is returned to the process station.

The novel features of the invention are set forth
20 with particularity in the appended claims. The invention will be best understood from the following description when read in conjunction with the accompanying drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 comprises a block diagram of a preferred embodiment of a delivery system for delivering RF-modulated electromagnetic energy to a solution;

5 Figure 2 is a graphical representation of how the zeta potential of a solution is modified as a function of the amplitude and duration of treatment with RF energy;

Figure 3 is a block diagram of a test bed for determining treatment parameter settings;

10 Figure 4 comprises a top level view of a tank showing a distribution of delivery apparatus and associated RF energy distribution;

Figure 5 comprises a side elevation view of the tank of Figure 4 along the plane 5 - 5;

15 Figure 6 is a block diagram of the signal generator of the preferred embodiment of Figure 1;

Figure 7 is a side elevation view of a preferred distribution of distribution apparatus in a tank along with sensors for monitoring the effectiveness of the treatment parameters;

20 Figure 8A is a transparent view of a first preferred embodiment of a delivery apparatus;

Figure 8B is a schematic cross section of the embodiment of Figure 8A;

25 Figure 9A is a transparent view of a second preferred embodiment of a delivery apparatus;

Figure 9B is a schematic cross section of the embodiment of Figure 9A;

30 Figure 10 is a transparent view of a third preferred embodiment of a delivery apparatus;

Figure 11 is a cross sectional view of the embodiment of Figure 10 along the plane 11 - 11;

Figure 12 is a partial cross sectional view of a fourth preferred embodiment of a delivery apparatus;

35 Figure 13 is a partial cross sectional view of a fifth preferred embodiment of a delivery apparatus;

Figure 14 comprises a block diagram of a preferred embodiment of a remote delivery system for delivering RF-modulated energy to a secondary solution by recirculating a



treated primary solution between the delivery apparatus and a process station containing the secondary solution;

Figures 15A-15C are block diagrams of alternative radiators for treating the secondary solution with radiation
5 from the primary solution;

Figure 16 is a block diagram of the delivery system of Figure 14 showing feedback control of the delivery apparatus;

Figure 17 is a block diagram of a second preferred
10 embodiment of a remote delivery system where the treatment station contains a tank of primary solution that is recirculated between the process station and the treatment station;

Figure 18 is a block diagram of a third preferred embodiment of a remote delivery system where the secondary
15 solution is recirculated from the process station to the treatment station where it is passed proximate to a primary solution contained within the delivery apparatus;

Figure 19 is a block diagram of a fourth preferred embodiment of a remote delivery system where the secondary
20 solution is recirculated from the process station to a tank in the treatment station having a delivery apparatus and a treated primary solution located within;

Figure 20 is a block diagram of a fifth preferred embodiment of a remote delivery system where the primary
25 solution passes unidirectionally past a delivery apparatus in the treatment station to a process station containing a secondary solution;

Figure 21 is an exemplary system for practicing the described method of treating a secondary solution by
30 recirculating a treated primary solution proximate to the secondary solution;

Figure 22 is a cross sectional end view of the delivery apparatus of Figure 21 along the plane 22 - 22; and

Figures 23A-23F are schematic diagrams
35 demonstrating additional design criteria that can be used in constructing delivery apparatus for treating a primary solution that is then used to treat a secondary solution.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention relates to an apparatus for delivering electromagnetic energy in the form of magnetic and electric fields into a colloidal suspension, i.e., a solution, for modifying its characteristics. As described in the
5 aforementioned paper by Zeta Meter, Inc., the characteristics of a solution can be desirably altered when its zeta potential is modified. It is believed that the ability to modify a
10 solution's characteristics, e.g., its zeta potential or any other appropriate measure, is improved when it is subjected to an RF-modulated magnetic field and an RF-modulated electric field. Thus, it is an object of the present invention to provide an improved system for delivering RF-modulated electromagnetic energy into a solution.

15 Figure 1 shows a block diagram of a delivery system 10, primarily comprised of a signal generator 12 and a delivery apparatus 14 contained within a solution 16, e.g., a fluid or gas. The signal generator 12 generates an RF-modulated signal 18 that drives the delivery apparatus 14. The delivery
20 apparatus 14, when stimulated by the RF-modulated signal 18, generates a magnetic field 20 and an electric field 22. As shown in Figure 2, some solution's characteristics, e.g., its zeta potential, alter as a function of the time duration and/or amplitude of the RF-modulated energy delivered into the
25 solution. However, modification of the zeta potential of the solution in response to RF-modulated energy reaches a valley 24 and reverses when an energy level increases beyond an optimal treatment point 26, as a function of the time duration and/or amplitude of the RF-modulated energy delivered. The
30 modification to the solution is believed to be time limited and thus decreases over time. Thus, preferred embodiments of the present invention apply RF-modulated energy for a first time period, remove the RF-modulated energy for a second time period and then repeat this application and removal pattern, defining a
35 duty cycle. The duty cycle and the amplitude cooperatively determine the rate that power is delivered into the solution.

As with most electromagnetic energy, the intensity of energy measured from the delivery apparatus 14 varies with distance. Thus, to uniformly treat the solution 16, the

distance from the delivery apparatus 14 and attributes of the RF-modulated signal 18 must be used in conjunction to select treatment parameters, e.g., time duration, duty cycle, amplitude, and distance, which determine a rate that power is applied to the majority of the solution and thus achieve the desired modification.

Delivery Apparatus	D = 0 V (estimated) Atmosphere	D = 6 in. V Water	D = 1 Ft. V Water	D = 4 Ft. V Water	D = 6 Ft. V Water
DA I	5000	12.0	6.0	2.0	1.0
DA II	10,000	25.0	18.0	12.0	8.0

TABLE I

Figure 3 shows a test bed 28 for determining the treatment parameters. The test bed 28 is comprised of a tank 30 that is filled with a test fluid 32 corresponding to the solution 16 that is to be treated. The delivery apparatus 14 is submerged within the fluid 32 and is driven by the signal generator 12 via the RF-modulated signal 18. A sensor 34, primarily comprised of a coil, is submerged within the fluid 32 a distance 36 away from the delivery apparatus 14. The sensor 34 is coupled via signal path 38 to a voltmeter 40 to measure the magnitude of RF energy coupled from the delivery apparatus 14 to the sensor 34 through the fluid 32. Voltages measured by the voltmeter 40 are believed to correspond to modifications of the fluid 32, e.g., its zeta potential. Using the test bed 28, measurements are taken to determine test data as listed above in Table I corresponding to various preferred embodiments of the delivery apparatus 14 (discussed further below). Accordingly, as shown in Figures 4 and 5, a plurality of delivery apparatus 14 are distributed in an actual treatment system tank 42 within a three dimensional matrix. By distributing the delivery apparatus 14 accordingly, radial arcs of treatment distance 44 containing a desired permissible range of RF energy can be positioned to encompass the majority of the solution 16 to be treated. Once the desired treatment distance 44 is chosen, the remaining treatment parameters, the time duration and amplitude of the RF-modulated signal 18, are interactively chosen



according to the test data to achieve the desired modification to the solution.

Figure 6 shows a block diagram of an exemplary signal generator 12, primarily comprised of an RF generator 46 which generates a fixed RF frequency, e.g., 27.225 MHz, a duty cycle controller 48 and a power amplifier 50. The power amplifier 50, under control of a power/amplitude adjustment 52, operates on an RF signal 54 input from the RF generator 46 and outputs a fixed amplitude signal to the delivery apparatus 14 via the RF-modulated signal 18 according to the selected treatment parameters. The duty cycle controller 48 controls the power amplifier 50 by modulating its output on and off. The duty cycle controller 50 is set according to an on adjustment 56 and an off adjustment 58 to generate the duty cycle according to the selected treatment parameters. The on and off adjustments 56, 58 are preferably adjustable in increments, e.g., one minute, up to a duration of sixty minutes. Thus, a typical setting of ten minutes on and sixty minutes off can be accommodated. While Figure 6 shows an exemplary signal generator 12, any other implementation that provides an RF-modulated signal to a delivery apparatus is considered to be within the scope of a signal generator for the present invention.

In a preferred embodiment, as shown in Figure 7, a plurality of sensors 34 are present permitting confirmation of the efficacy of the settings of the treatment parameters in its actual environment. However, it is recognized, that sensors 34 only read voltages that are indicative of the effectiveness of the delivery system 10 which operates in an open loop manner. Thus, in an alternative embodiment, the sensors 34 are replaced by sensors that directly determine the modification to the solution, e.g., its zeta potential value. In this alternative embodiment, a potential processor 60 (see Figure 6) reads the achieved modification to the solution, e.g., its zeta potential, and accordingly modifies the duty cycle controller 48 and the power amplifier 50 by interactively determining preferred settings for the on adjustment 56, the off adjustment 58 and the power amplitude adjustment 52. Thus, closed loop control is achieved in this alternative embodiment.



As referenced above in the discussion of Table I, the effectiveness of the delivery system 10 is determined by the treatment parameters which are set according to the characteristics for selected delivery apparatus 14 in solution 16. A first preferred delivery apparatus 70, referenced in Table I as DA I, is shown in Figure 8A. The delivery apparatus 70 is primarily comprised of 1) a water-tight, tubular housing 72, preferably cylindrical, 2) a transformer 74 contained within the housing, 3) first and second voltage probe discs 76 and 78 coupled to the transformer 74 and 4) a coaxial cable 80 coupled to the transformer 74 in the housing 72 through a first water-tight seal 82 and passing the RF-modulated signal 18 from the signal generator 12. As also shown in the schematic representation of Figure 8B, the transformer 74 is comprised of a primary coil 84 inductively coupled to a secondary coil 86, and having voltage probe discs 76 and 78 coupled to the secondary coil 86, preferably at its ends. The primary and secondary coils 84 and 86 are wound around a tube 88 which is preferably formed of a non-conductive material, e.g., PVC. The primary coil 84 is preferably wound around a portion of the secondary coil 86, and is maintained in electrical isolation from the secondary coil 86 by an insulator 90 or alternatively by forming the coils from insulated conductors. The RF-modulated signal 18 is preferably coupled to the primary coil 84 through a high "Q" variable capacitor 92 which is set to a value to match the impedance of the delivery apparatus 70 to the signal generator 12. When the primary coil 84 is powered by the RF-modulated signal 18, magnetic field 20, also referred to as an H-field, is generated primarily from the secondary coil 86 and extends beyond the delivery apparatus 70 and into the solution 16. The secondary coil 86, as a consequence of inductive coupling to the primary coil 84, generates a voltage (measured between electrical ends 94 and 96) having an amplitude larger than the voltage presented to the primary coil 84 from the RF-modulated signal 18. The voltages from electrical ends 94, 96 are coupled to voltage probe discs 76 and 78, respectively. The voltage probe disc 76 is contained within a first non-conductive water-tight chamber 98 formed at a first end of the housing 72. A first non-conductive inner end plate



100 is sealed at a first inner position of the housing 72 and a first non-conductive thin outer end plate 102, proximate to the first end of the housing 72, is sealed at the first end of the housing 72 to form the chamber 98. The electrical end 94 of the
5 secondary coil 86 is coupled to the voltage probe disc 76 through a second water-tight seal 104. Similarly, a second non-conductive water-tight chamber 106 is formed at the second end of the housing 72 between second inner end plate 108 and second outer end plate 110, having the second voltage probe disc 78
10 contained within and coupled via a third water-tight seal 112 in second inner end plate 108 to electrical end 96. The chambers 98, 106 are preferably filled with a fluid 114, e.g., de-ionized water (DI). It is believed that coupling the electric field 22, into the fluid-filled chambers 98, 106 and through thin outer
15 end plates 102, 110 before coupling the electric field 22 to the solution 16, improves the delivery of the electric field 22 to the solution 16. Also, by maintaining the voltage probe discs 76, 78 in electrical isolation from the solution 16, signal loading is reduced. Sections of the housing 72 which form the
20 first and second water-tight chambers 98, 106 are preferably made from non-conductive materials, e.g., PVC. However, the wall section of housing 72 surrounding transformer 74, i.e., between inner end plates 100, 108 can alternatively be fabricated from non-conductive, e.g., PVC, or conductive
25 materials, e.g., copper.

Figures 9A and 9B show a second alternative embodiment 120 of the delivery apparatus 14, referred to as DA II in Table I. The delivery apparatus 120 is primarily comprised of 1) water-tight, tubular housing 72, preferably
30 cylindrical, 2) a tapped coil 122 contained within the housing, 3) a voltage probe disc 124 coupled to a first end of the tapped coil 122 and 4) coaxial cable 80 coupled to the tapped coil 122 within the housing 72 through first water-tight seal 82 and passing the RF-modulated signal 18. The coaxial cable 80 is
35 preferably coupled to a second end of the tapped coil 122 and to an intermediate tap point 126 through high "Q" variable capacitor 92, adjusted to match the impedance of the delivery apparatus 120 to the signal generator 12. The tapped coil 122 generates magnetic field 20 that extends into the solution 16



surrounding the delivery apparatus 120. A voltage measured between points 128 and 130 is inductively generated by the tapped coil 122 and is greater in amplitude than the RF-modulated signal 18 input to the tapped coil 122. The voltage at point 128 is coupled to the voltage probe disc 124, contained within a water-tight chamber 132 at the first end of the water-tight housing 72. A non-conductive inner end plate 134 is sealed at a first inner position of the housing 72 and a non-conductive thin outer end plate 136, proximate to the first end of the housing 72, is sealed at the first end of the housing 72 to form the water-tight chamber 132. The voltage generated at the first end of the tapped coil 122 is coupled to the voltage probe disc 124 through a second water-tight seal 138. The chamber 132 is preferably filled with fluid 114, e.g., de-ionized water (DI). As with the previously described embodiment, it is believed that this structure improves the coupling of the electric field 22 into the solution 16, while minimizing the electrical load. As previously described, the section of the housing 72 which forms the water-tight chamber 132 is preferably made from a non-conductive material, e.g., PVC. However, the wall section of housing 72 surrounding the tapped coil 122 can alternatively be fabricated from a non-conductive, e.g., PVC, or conductive, e.g., copper, material.

Figures 10 and 11 show a third alternative embodiment 140 of delivery apparatus 14. The delivery apparatus 140 is primarily comprised of 1) water-tight, tubular housing 72, preferably cylindrical, 2) tapped coil 122 contained within the housing, 3) a voltage coupling structure 142 containing a voltage coupling plate 144 coupled to a first end 146 of the tapped coil 122, and 4) coaxial cable 80 coupled to the tapped coil 122 in the housing 72 through first water-tight seal 82 and passing the RF-modulated signal 18. Essentially, the structure of the water-tight housing 72 and the tapped coil 122 are identical with the previously-described embodiment 120 shown in Figure 9A. However, in this embodiment, the additional voltage coupling structure 142 is comprised of a second housing 148 coupled to a bladder 150, preferably flexible, forming a water-tight assembly with a fluid coupling passageway 152 inbetween. The voltage coupling plate 144 is contained within the second



housing 148 and is electrically coupled to the first end 146 of the tapped coil 122 using conductor 154 which passes through a second water-tight seal 156. The voltage coupling structure 142 is preferably filled with fluid 114, e.g., de-ionized water (DI), using a filler tube and cap 158. While the voltage coupling structure 142 is being filled with fluid 114, air within is vented through an exhaust port 160. The voltage coupling structure 142 and specifically the bladder 150 are preferably formed as an arcuate surface 162 to match an outer surface, e.g., a curved tank or pipe, thus facilitating treatment of the solution 16 contained within. Thus, in this embodiment, the solution 16 is treated with magnetic and electric fields, respectively 20 and 22, without the delivery apparatus 140 having contact with the solution 16. As previously described, housing 72 may alternatively be fabricated from a non-conductive, e.g., PVC, or conductive, e.g., copper, material.

Figure 12 shows a fourth alternative embodiment 170 of delivery apparatus 14. The delivery apparatus 170 is primarily comprised of an RF generator assembly 172, 2) a helical resonator 174, and 3) a voltage probe assembly 176, all contained within a water-tight housing 178. The RF generator assembly 172, is somewhat analogous to the previously described signal generator 12 in that it generates an RF-modulated signal. A power control cable 180 delivers modulated power, i.e., adjustable in voltage and duty cycle, to the RF generator assembly 172 to cause the RF generator assembly to deliver RF-modulated energy via conductors 182, 184 to the helical resonator 174, i.e., a tapped coil. The close proximity of the RF generator assembly 172 to the helical resonator 174 improves signal delivery. The helical resonator 174, generates a high voltage signal at its end 186 to the voltage probe assembly 176 in a similar manner to the previously described tapped coil 122. The helical resonator 174 is preferably formed of a metallic coil formed from a length of conductive wire, e.g., copper, having an unwound length of one quarter of the wavelength of the RF signal (e.g., approximately 8.62 feet @27.225 MHz). A non-conductive, e.g., polycarbonate, adjustment rod 188 is coupled to the end 186 of the helical resonator 174 and adjustably



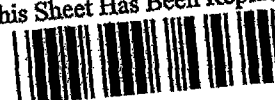
passes through end plate 190. By altering the relative position of the adjustment rod 188, the linear size of the helical resonator 174 is altered to adjust the impedance of the resonator 174 and improve signal matching to the RF generator assembly 172.

The voltage probe assembly 176 is primarily comprised of 1) a non-conductive, e.g., Teflon, outer hollow housing 192, preferably spherical, forming a matching chamber 194 within, 2) a conductive, e.g., gold-plated brass, voltage probe 196 contained within the housing 192, and a conductive standoff 198, coupled at a first end to the voltage probe 196, e.g., via a threaded coupling, and forming a water-tight seal to the housing 192. The second end of the conductive standoff 198 is coupled to end 186 of the helical resonator 174 providing a conductive path between the resonator 174 and the voltage probe 196. A fluid 200, e.g., de-ionized water (DI), surrounds the voltage probe 196 within the chamber 194.

The structure of the water-tight housing 178 is divided into three sections. In first and second sections 202, 204 surrounding the voltage probe assembly 176 and the RF generator assembly 172, the walls of the housing 178 are formed of a non-conductive material, e.g., plastic. However, the third section 206 of the housing 178 forms a shield, preferably cylindrical and fabricated from a conductive material, e.g., copper, to contain the electrical field.

Figure 13 shows a fifth alternative embodiment of delivery apparatus 14. This embodiment is primarily comprised of the previously described voltage probe assembly 176 coupled via a shielded cable 212 having a length preferably equal to $1/4$ of the wavelength of the RF signal (e.g., approximately 7.9 feet @27.225 MHz and differing from the prior embodiment due to the characteristics of the cable) to an RF generator/matching network 214, similar in function and structure to the RF generator assembly 172 but physically remote from the voltage probe assembly.

As disclosed above, the characteristics of a solution, e.g., a fluid or gas, can be desirably altered by treating a solution with RF-modulated energy. It has been shown that the effects of treating a solution with RF-modulated energy



endure for a substantial period of time, i.e., minutes as opposed to microseconds. Thus, further experimentation proceeded to determine any additional aspects of this treatment. Consequently, it was determined that if a first solution, i.e.,
5 a primary solution, is treated and subsequently transported to a remote location and placed proximate to a secondary solution, the characteristics of the secondary solution are similarly effected, e.g., secondary emissions from the primary solution effect the characteristics of the secondary solution. The
10 following experiments were conducted:

Solution p (primary) was treated by delivering a high voltage electromagnetic signal into a container holding solution p. A portion of the treated solution p was then transported to another room which was approximately 50 feet away
15 and placed in a bottle which was placed near a beaker which contained a solution s (secondary) of nitric acid. A pH electrode was located in the secondary beaker during this experiment. Before placing solution p near the beaker with solution s, the pH was constant at 4.341 ± 0.002 for at least 30
20 minutes. Fifteen minutes after placing solution p near the beaker with solution s, the pH was fluctuating and afterwards started to continuously drift downwards, changing to a pH of 4.128 after 2 hours of exposure. This experiment was repeated three times.

In a similar experiment, 20 mg of rutile was placed in a beaker (solution s). After 24 hours, its zeta potential was measured. The zeta potential remained at 7 ± 2 mV for at least one hour. After that, a container of solution p which had been treated with a high voltage electromagnetic
30 signal was placed in a bottle near solution s. The zeta potential of rutile in solution s started to fluctuate between 22 and 6 mv with time after exposure, i.e., being placed in close proximity to solution p. This fluctuation persisted for at least 2 hours. Atomic force microscopy was used to measure
35 the surface forces at the atomic interface of zinc colloids and a solid silica surface. A non-energized solution (solution s) consistently exhibited positive force vectors out to a distance of 30 nanometers from the surface. The same solution was exposed to bottles of treated water (solution p) for a period of



20 minutes and the force vectors reversed their direction, becoming negative up to 9 nanometers, where it remained at 0 out to a distance of 100 nanometers.

In another experiment, tap water was placed into two glass beakers (#1 and #2) of equal diameter. The water content in each beaker was measured and equalized to $100 \pm .011$ grams. While, beaker #1 was kept isolated from the treated water, beaker #2 was exposed (e.g., by secondary emissions) to treated water (solution p). Both beakers were allowed to stand and their weight was measured at 1 hour intervals in two controlled environments (30°C with no ventilation but open to the atmosphere). Beaker #1 (the untreated beaker) lost weight at 1.84 times the rate of beaker #2. The experiment was repeated ten times in three hours with results repeating within $\pm 3\%$.

In yet another experiment, surface tension was recorded with secondary water and oscillations occurring from 75 mN/m (millinewtons/meter) to 77.5 mN/m.

In yet another similar experiment, a precipitation of calcium carbonate was measured by measuring its turbidity upon mixing 10 ml of 0.003 M calcium nitrate and 10 ml of 0.005 M sodium carbonate. The turbidity first increased and after reaching a plateau decreased with time (e.g., a nucleation and precipitation reaction). In a next experiment, the solutions of calcium nitrate and sodium carbonate (solution s) were exposed to a similarly treated solution p for a period of ten minutes prior to mixing. The maximum turbidity was observed to decrease significantly in the presence of secondary emissions. Particles precipitated under exposure to solution p exhibited a larger mean particle size (as measured by optical microscopy).

The effects of shielding barriers on secondary emissions from solution p were also studied. From these studies it was determined that it was preferable to use a metallic shield, e.g., copper, μ metal, etc., to limit the secondary emissions from treating any solutions other than the secondary solution.

To evaluate the strength of the secondary emissions, pH was again measured versus time in solution s. In one experiment, solution p was treated with electromagnetic



energy and a bottle in which solution p was contained was enclosed in three sheets of aluminum foil. The pH of solution s held constant at 4.349 ± 0.002 for at least 30 minutes. After placing a bottle with solution p nearby, the pH of solution s
5 changed from 4.349 to 4.193 in 2 hours. This experiment was repeated three times with a reproducibility of ± 0.01 pH units.

In yet another experiment, the bottle with treated solution p was placed inside an aluminum container with 1/8 inch thick walls. The pH of solution s was initially constant at
10 4.160, but 1 hour after placing solution p nearby (inside a container) it changed to 4.195 and it continued to increase.

In yet another experiment, the bottle with treated solution p was placed inside a stainless steel container with 1/8 inch thick walls. The pH of solution s was constant at
15 4.420. After solution p inside the container was placed nearby, the pH of solution s changed from pH 4.420 to 4.469.

From these experiments, it was concluded that a mechanism existed where once a primary solution was treated with electromagnetic radiation, that transporting the primary
20 solution proximate to a secondary solution could treat the secondary solution, e.g., by secondary emissions from the primary solution.

Figure 14 shows a block diagram of a treatment system 310 that embodies the present invention, primarily
25 comprised of: 1) a treatment station 312 for treating a primary solution 314, 2) a process station 316 containing a secondary solution 318 that is to be treated, where the process station 316 is preferably located remote from the treatment station 312, and 3) a transporting apparatus 320 for transporting the treated
30 primary solution 314 proximate to the secondary solution 318. The treatment station 312 preferably contains a delivery apparatus 322 for generating electromagnetic energy and treating the primary solution 314. An exemplary delivery apparatus 140 (see Figure 11) delivers electromagnetic energy into an energy
35 receiving primary solution (see fluid 114 in Figure 11) contained within the bladder 150 preferably surrounding a pipe 324 (see Figure 14). The primary solution 314 contained within the pipe 324 receives radiation 326 which modifies the primary solution 314. Consequently, the primary solution 314 can then



emit secondary radiation 328 (actually tertiary radiation relative to the original radiation into the energy receiving primary solution 114) to treat the secondary solution 318 from a radiator loop 330.

- 5 The primary solution 314 is preferably recirculated between the treatment station 312 and the process station 316 by passing the primary solution 314 within the pipe 324 using an apparatus for maintaining flow of the primary solution, e.g., a circulating pump 332. Although, it is
- 10 preferable to recirculate the primary solution 314, it is not necessary to practice the present invention. Embodiments which unidirectionally transport the primary solution 314 from the treatment station 312 to the process station 316 are also considered within the scope of the present invention.
- 15 Embodiments which recirculate the primary solution are believed to be more efficient. Not all of the energy delivered into the primary solution 314 can be imparted to the secondary solution 318 when solution 314a is transported proximate to the secondary solution 318. Thus, the primary solution 314 will still retain
- 20 some of the RF-modulated energy imparted to it by the delivery apparatus 322. Consequently, by recirculating the partially depleted primary solution 314b back to the delivery apparatus, it will take less energy to re-treat the primary solution 314b.

- The extent of treatment of the secondary solution
- 25 is somewhat dependent upon the proximity and duration of exposure of the primary solution 314 to the secondary solution 318. Figures 15A-15C show exemplary radiators 334, 336, 338 for exposing the secondary solution 318 to radiation 328 from the primary solution 314. Radiator 334 comprises an extended
- 30 radiator loop 330 which increases the coupling, i.e., the efficacy of treating the secondary solution from the primary solution, due to its increase in path length and/or having multiple passes compared to the single loop of the radiator loop 330 implementation. Radiator 336 increases the number of paths
- 35 and thus the volume of the secondary solution 318 being directly treated by secondary emissions 328 from the primary solution 314. However, due to the increase in the number of paths, the solution's velocity is correspondingly decreased. This decrease in velocity exposes the secondary solution 318 to each portion



of the primary solution 314 for a longer period of time. Radiator 338 exposes a larger volume by having a large cross-sectional surface area (e.g., a hexagon as shown in this example) that also enables a large volume of secondary solution to be directly subjected to secondary radiation 328 from the primary solution 314. Again, this increased exposure area results in a lower velocity for the primary solution 314 within the radiator 338. One of ordinary skill in the art can envision other radiator configurations that trade off the amount of exposure and the velocity of the primary solution 314.

As disclosed above, a feedback mechanism is preferably used to determine the optimal treatment level for the solution. In the present invention, it is the treatment level of primary solution 314 that is preferably modified in response to secondary effects of treating the secondary solution 318. Therefore as shown in Figure 16, a sensor 340 is preferably placed in the secondary solution 318 and coupled via feedback signal 342 to drive electronics 344 (for example, see signal generator 12 in Figure 6) which drives the delivery apparatus 322. The sensor 340 can alternatively measure pH, zeta potential or any other measure that determines the amount of treatment required. As described above, the drive electronics 344 can alter the duty cycle, frequency, amplitude, etc. of the RF-modulated energy applied to the delivery apparatus 322. Additionally, the recirculation speed of the primary solution 314 can be altered by changing the speed of the circulating pump 332 in response to the feedback signal 342. Although placing the feedback sensor 340 in the secondary solution 318 is preferred, feedback control can also be achieved with a feedback sensor placed in the primary solution 314 to measure the amount of treatment of the primary solution 314 (which corresponds to the amount of treatment of the secondary solution 318).

Once the secondary solution is treated, it can beneficially modify its performance in various processes. An exemplary subset is described below in reference to Figure 14:

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1. Changing Colloid Behavior in Cooling / Service
 Water Systems (Scale Control), e.g., Cooling Tower
 Descaling

The energy source, e.g., the delivery apparatus 322, stimulates
5 the primary solution 314 using a magnetic, electromagnetic, or
electric field, a visible or invisible broadband or
monochromatic light or any other energy source. The primary
solution 314 is thus placed into an altered energy state, and is
transferred by a pump 332 or other means through closed loop
10 pipe 324, tubing, etc. into the sump or holding tank 316
containing the coolant secondary solution 318. Energy emanating
from the primary solution 314 is then radiated into the
secondary solution 318, altering the physical characteristics of
the secondary solution 318, i.e., pH, conductivity, zeta
15 potential, surface tension, hydration force or any other
characteristic of the secondary solution 318 to effect the
attractiveness of colloidal particles in the secondary solution
318 to surfaces in the system. By applying the proper energy
profile, scale particles will be repelled from surfaces
20 contacting the secondary solution 318, inhibiting the formation
of new scale, and promoting the removal of pre-existing scale
buildup.

2. Printing Ink Treatment (Changing Font/ Surface
25 Adhesion Characteristics)

The energy source, e.g., the delivery apparatus 322, stimulates
the primary solution 314 using a magnetic, electromagnetic, or
electric field, visible or invisible broadband or monochromatic
light or any other energy source. The primary solution 314 is
30 thus placed into an altered energy state, and is transferred by
a pump 332 or other means through closed loop pipe 324, tubing,
etc. into the sump or holding tank 316 containing the ink or
font secondary solution 318. Energy emanating from the primary
solution 314 is then radiated into the secondary solution 318,
35 altering the physical characteristics of the secondary solution
318, i.e., pH, conductivity, zeta potential, surface tension,
hydration force or any other characteristic of the secondary
solution 318 to effect the attractiveness of colloidal particles
in the primary solution 314 to the print medium. By applying



the proper energy profile, ink or toner particles will be attracted to the printing media, resulting in improved print density, or more economical usage of ink or fonts.

5 3. De-inking of Pulp in Paper / Cardboard Recycling Processing / Removal of Ink or other Particles from Paper Slurry

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or
10 electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the process container tank 316 containing the process
15 slurry 318. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary
20 solution 318 to effect the attractiveness of colloidal particles in the secondary solution 318 to each other or to filter, skimmer, or other process elements. By applying the proper energy profile, ink, toner, or other particles will be either attracted to filter media, or be agglomerated as a froth at the
25 surface to be skimmed off and disposed of.

4. Industrial Chemistry Process Enhancements / Chemical Process Synthesis Treatment

The energy source, e.g., the delivery apparatus 322, stimulates
30 the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing,
35 etc. into the process container tank 316 containing the process solution 318. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension,



hydration force or any other characteristic of the secondary solution 318 to stimulate certain chemical reactions, or cause some enhancement of catalytic or other desired changes of chemistry.

5

5. Treating Water for Improvement of Strength of Concrete / Aggregate Mixes

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the process container/tank 316 containing the mix water 318. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318 altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary solution 318 to alter the curing time, the cured strength, the permeability, the porosity, or any other desirable effects of the finished concrete, including eliminating common salt types of additives which can attack and weaken reinforcing and metallic members in the pour.

25

6. Water Treatment to Enhance Plant Growth Cycles / Treatment of Water Agriculture / Plant Biology

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the process container/tank 316 containing the irrigation water 318. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the



secondary solution 318 to alter plant growth rates, plant size, fruit size and/or quality, plant susceptibility to disease or pests, plant water and nutrient requirements, and any other desirable effects on the plant species.

5

7. Medical / Biological Transfer and Treatment Techniques

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the treatment head / culture growth area / implant 316. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary solution 318 to alter cell growth rates, inhibit the growth of damaged or aberrant cells, stimulate the immune system function, stimulate the mending of broken bones, allow the removal of calcium deposits such as spurs, or allow removal of arterial plaque.

25

8. Wastewater / Effluent Treatment Using Energy Exchanger System

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the treatment pond / sump / stream 316. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary



solution 318 to effect precipitation, flocculation or agglomeration of particles suspended in the wastewater effluent, allowing them to be sedimented, skimmed or filtered from the solution.

5

9. Liquid Hydrocarbon Fuel Treatment for Improved Combustion

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or
10 electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the fuel storage tank 316, an in-line fuel treatment
15 cell or into the carburetion or induction systems. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension,
20 hydration force or any other characteristic of the secondary solution 318 which to modify complex hydrocarbon chains by cracking, molecular re-organization or attachment of OH radicals to improve the combustibility, modify the burn time or in any other way improve fuel economy or lower unwanted emissions of
25 pollutants, including reduction of oxides of nitrogen, unburnt carbon or any other undesirable by-products of combustion.

10. Energy Treatment for an Icemaking Feedwater / Process

30 The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by
35 a pump 332 or other means through closed loop pipe 324, tubing, etc. into the icemaker feedwater holding tank 316, or icemaker water sump. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e.,



pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary solution 318 to effect the crystalline structure of ice to alter visual quality, melt time, entrainment of gasses, or other qualities of the ice.

11. Energetic Treatment of Steam / Water Vapor /
Condensate Systems for Controlling Scale and
Corrosion

10 The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by
15 a pump 332 or other means through closed loop pipe 324, tubing, etc. or water sump. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface
20 tension, hydration force or any other characteristic of the secondary solution 318 to effect the formation of scale or corrosion in boiler tubes / steam / condensate systems in boilers, industrial steam / low pressure vapor systems or other heat transfer surfaces.

25

12. System for Energetic Treatment of Injected Fuel
Additives

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or
30 electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the injector solution additive holding tank 316.
35 Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary



solution 318 to effect the characteristics of that solution when injected into the fuel source, induction system or combustion chamber, to improve fuel characteristics, reduce unwanted exhaust emissions, modify fuel burn characteristics, reduce pinging and knock or otherwise improve engine performance.

13. Treatment of Water in De-Salination Systems

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the de-salination system inlet water 318. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary solution 318 to effect the characteristics of salt water such that colloidal particles will flocculate or agglomerate allowing pre-filtration of the water by such means as large mesh mechanical filtration or centrifugation.

14. Treatment of Chemistry in Semiconductor Deposition Systems

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the deposition system holding tank 316. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary solution 318 to effect the characteristics of surface attraction



to deposition solution colloidal particles, such that thinner and more uniform coatings can be applied.

15. Enhancement in Photographic Emulsions /
5 Photodevelopment Cycles, e.g., in Semiconductor
 Deposition Systems

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic
10 light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the deposition system holding tank 316. Energy emanating from the primary solution 314 is then radiated into
15 the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary solution 318 to effect the characteristics of the quality and
20 size distribution of colloidal particles in photographic emulsions to improve grain size and color rendition and to treat various solutions used in development and processing to improve the rate of absorption / uniformity of development to enhance image quality and throughput times.

25 16. Improvement of Paint Application Adhesion and
 Curing

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or
30 electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the system holding tank 316. Energy emanating from
35 the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary solution 318 to effect the



characteristics of the quality and size distribution of colloidal particles in paint emulsions during manufacture and application of paints to control pigment size distribution, base polymer characteristics as well as sag, coating thickness, 5 drying time, finish quality, and hardness.

17. Enhancement of Electroplating Processes

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or 10 electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the plating solution / plating tank 316. Energy 15 emanating from the primary solution 314 is then radiated into the secondary solution 318, altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary 20 solution 318 to effect the characteristics of the plating solution to control the purity, density and porosity of electroplated surfaces.

18. Treatment of Water to Reduce Evaporative Loss in
25 Agricultural Irrigation

The energy source, e.g., the delivery apparatus 322, stimulates the primary solution 314 using a magnetic, electromagnetic, or electric field, visible or invisible broadband or monochromatic light or any other energy source. The primary solution 314 is 30 thus placed into an altered energy state, and is transferred by a pump 332 or other means through closed loop pipe 324, tubing, etc. into the process container/tank 316 containing the irrigation water 318. Energy emanating from the primary solution 314 is then radiated into the secondary solution 318, 35 altering the physical characteristics of the secondary solution 318, i.e., pH, conductivity, zeta potential, viscosity, surface tension, hydration force or any other characteristic of the secondary solution 318 to effect the rate at which water is



absorbed by soil growth medium and reduce water usage and thus increase profitability of agri-business.

While it is preferable to recirculate a primary solution 314 which is isolated from the secondary solution 318
5 between the treatment station 312 and the process station 316, any system that transports a solution between stations 312 and 316 to facilitate treatment by secondary emissions is considered to be within the scope of the present invention. Figures 17-20
10 are exemplary embodiments of systems that treat a secondary solution 318 by causing the treated primary solution 314 to be located proximate to the secondary solution 318.

For example only, Figure 17 shows a treatment system 310 where the primary solution 314 is contained within the treatment station 312. The treated primary solution 314 is
15 recirculated in pipe 324 between the treatment station 312 and the process station 316 where the secondary solution 318 is treated. In this example, the primary 314 and secondary 318 solutions are isolated from each other.

Conversely, Figure 18 shows a treatment system 310
20 where the secondary solution 318 is recirculated in pipe 324 between the process station 316 and the treatment station 312. At the treatment station 312, the secondary solution 318 is treated by secondary emissions from a primary solution 314. In this example, the primary solution 314 is alternatively
25 contained within a tank in the treatment station 312 or is the solution contained within the delivery apparatus 322 (e.g., see fluid 114 in Figure 11). In either case, the primary 314 and secondary 318 solutions are isolated from each other.

Figure 19 shows a treatment system 310 where the
30 secondary solution 318 is passed bidirectionally between the process station 316 and the treatment station 312 using a pair of circulating pumps 332a and 332b. In this example, the primary solution 314 is the solution contained within the delivery apparatus 322 (see fluid 114 in Figure 11), isolated
35 from the secondary solution 318. The treated secondary solution within the tank at the treatment station 312 is mixed with untreated secondary solution within the tank at the process station 316 and consequentially treats the remaining secondary solution.

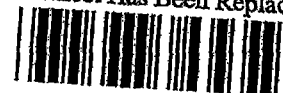


Figure 20 shows a treatment system 310 where a primary solution 314 passes unidirectionally from the treatment station 312 where it is treated using the delivery apparatus 322 with RF-modulated energy to the process station 316 where the
5 secondary solution 318 is treated with secondary radiation 326 from the primary solution 314.

Figure 21 shows an exemplary system 350 for practicing the above described method. In this system, a delivery apparatus 352, similar to that described in reference
10 to Figure 12, is modified to permit a recirculation pipe 354 to pass the primary solution 314 through the chamber 194 surrounding the voltage probe 196. (See Figure 22 for a cross sectional end view of the delivery apparatus 352 to see the relationship between the recirculation pipe 354 and the chamber
15 194). As previously described, the voltage probe 196 is subjected to RF-modulated energy which treats the surrounding solution in the chamber 194. However, in this embodiment the surrounding primary solution 314 is recirculated through pipes 354 and 324 using the circulating pump 332. The recirculated
20 primary solution 314 is circulated through a remote primary solution tank 356, somewhat analogous to the previously-described radiator loop 330, that is located in close proximity to a process solution tank 358 which contains the secondary solution 318. In this embodiment, the combination of the
25 primary solution tank 356 and the process solution tank 358 form the process station 316. Due to the quantity of treated primary solution 314 being present in the primary solution tank 356 and its proximity to the process solution tank 358, sufficient secondary radiation 326 can remotely treat the secondary
30 solution 318 in the process station 316.

It has been disclosed that secondary radiation from a treated primary solution can modify the characteristics of a secondary solution placed in close proximity. Additionally, it has been disclosed that shielding can effect
35 this transfer of secondary radiation. Therefore, it is believed to be preferable to shield the portions of the pipe 324 between the treatment station 312 and the process station 316 (see Figure 16) that contain the recirculated treated primary solution as well as the treatment station 312 and the drive



electronics 344 to limit the exposure by secondary radiation of any additional solutions that might be located proximate to the treatment system 310.

While the presently-preferred embodiments of
5 delivery apparatus have been described above, Figures 23A-23F show some additional design criteria that can be used in constructing additional delivery apparatus that treat a fluid, i.e., the primary solution 314, that is then used to treat a secondary solution 318.

10 In Figure 23A, a fluid 370 is contained or circulated between two metallic plates 372 and 374 independently driven by RF-modulated signals 376 and 378. Each plate is preferably covered with a thin dielectric coating 380 such that there is no galvanic connection between fluid 370 and the field
15 plates 372 or 374.

In Figure 23B, the fluid 370 is contained or circulated between the two metallic plates 372 and 374 independently driven by RF-modulated signals 376 and 378. In this embodiment, only one plate, e.g., 372, is covered with a
20 thin dielectric coating 380 such that there is a galvanic connection between the fluid 370 and one field plate, e.g., 372, only.

In Figure 23C, the fluid 370 is contained or circulated between the two metallic plates 372 and 374
25 independently driven by RF-modulated signals 376 and 378. However, in this embodiment, neither plate is coated with a dielectric coating and thus each plate has a galvanic connection to the fluid 370.

In Figure 23D, the fluid 370 is contained or
30 circulated between the two metallic plates 372 and 374 independently driven by RF-modulated signals 376 and 378. In this embodiment, the surface area of the metallic plates, proximate to the fluid 370, is extended to increase exposure of the fluid 370 to RF-modulated energy from signals 376 and 378.
35 The metallic plates and may have coatings as described in reference to Figures 23A-23C.

In Figure 23E, the fluid 370 is contained or circulated through a conductive tube or pipe 382 having a center electrode 384. The conductive pipe 382 and the center electrode



384 are independently driven by RF-modulated signals 376 and 378. The conductive pipe 382 and the center electrode 384 may have coatings as described in reference to Figures 23A-23C.

In Figure 23F, the fluid 370 is contained or
5 circulated between multiple metallic plates 386, 388, 390 and
392 independently driven by RF-modulated signals 394, 396, 398
and 400. The metallic plates may have dielectric coatings as
described in reference to Figures 23A-23C. Two or more of the
RF-modulated signals are preferably phase shifted to create a
10 rotating electric field in the fluid 370.

Although the present invention has been described in detail with reference only to the presently-preferred embodiments, those of ordinary skill in the art will appreciate that various modifications can be made without departing from the invention. For example, one of ordinary skill in the art can envision other systems that cause the primary 314 and secondary 318 solutions to be transported proximate to each other to remotely treat the secondary solution. Additionally, one can envision any of the disclosed embodiments combined with any of the disclosed radiators, or equivalents, to improve the efficacy of the delivery apparatus. Accordingly, the invention is defined by the following claims.

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CLAIMSWe claim:

1. Apparatus for delivering electromagnetic energy into a solution, comprising:

a first tubular housing having closed ends defining a first water-tight chamber;

coil means contained within said first chamber; said coil means delivering a magnetic field into the solution;

voltage probe means coupled to said coil means for delivering an electric field into the solution; and

means for coupling an electromagnetic signal to said coil means.

2. The apparatus of claim 1, wherein said voltage probe means is maintained within said apparatus, electrically isolated from the solution.

3. The apparatus of claim 2, wherein said voltage probe means comprises:

an inner non-conductive plate coupled to an inner surface of said first housing and defining a first end of said first chamber;

an outer non-conductive surface coupled to a first end of said first housing and defining a second water-tight chamber between said inner and outer plates and said first housing;

an electrically conductive plate contained within said second chamber for delivering an electric field into the solution;

a conductor for coupling said plate to said coil means; and

sealing means for passing said conductor from said first chamber containing said coil means to said second chamber containing said plate.

4. The apparatus of claim 3, wherein said second chamber is filled with a fluid.





5. The apparatus of claim 4, wherein said fluid is de-ionized water.

6. The apparatus of claim 3, wherein said coil means is comprised of a conductive tapped coil having a first end, a second end and an inner tap; said electromagnetic signal coupled to said first end and said inner tap and said voltage probe means coupled to said second end.

7. The apparatus of claim 3, wherein said coil means is comprised of a conductive primary coil electrically coupled to said electromagnetic signal and a conductive secondary coil inductively coupled to said primary coil; said voltage probe means coupled to said secondary coil.

8. The apparatus of claim 1, wherein said coil means is comprised of a conductive primary coil electrically coupled to said electromagnetic signal and a conductive secondary coil inductively coupled to said primary coil; said voltage probe means coupled to said secondary coil.

9. The apparatus of claim 3, wherein said coil means is comprised of a conductive tapped coil having a first end, a second end and an inner tap; said electromagnetic signal coupled to said first end and said inner tap and said voltage probe means coupled to said second end.

10. The apparatus of claim 2, wherein said voltage probe means comprises:

a second water-tight housing coupled to an outer surface of said first housing; said second housing having an inner surface defining a second chamber;

an electrically conductive plate contained within said second chamber for delivering an electric field into the solution;

a conductor for coupling said plate to said coil means; and





sealing means for passing said conductor from said first chamber containing said coil means to said second chamber containing said plate.

11. The apparatus of claim 10, wherein said second chamber is filled with a fluid.

12. The apparatus of claim 11, wherein said fluid is de-ionized water.

13. The apparatus of claim 11, additionally comprising a third non-conductive water-tight housing coupled to said second housing; said third housing defining a third chamber coupled to said second chamber via a common passageway.

14. The apparatus of claim 13, wherein said second and third chambers are filled with a fluid.

15. The apparatus of claim 14, wherein said fluid is de-ionized water.

16. The apparatus of claim 13, wherein said third housing has an outer arcuate surface for external coupling to a pipe, tank or other curved surface.

17. The apparatus of claim 1, wherein said coil means increases the amplitude of said electromagnetic signal coupled to said voltage probe means.

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18. A system for delivering electromagnetic energy into a solution, comprising:

a signal generator for generating a modulated RF signal output;

a first tubular housing having closed ends defining a first water-tight chamber;

coil means contained within said first chamber for delivering a magnetic field into the solution;

voltage probe means coupled to said coil means for delivering an electric field into the solution; and

means for coupling said modulated RF signal to said coil means.

19. The electromagnetic delivery system of claim 18, wherein said signal generator comprises:

means to set the amplitude of said RF signal; and

means to set the duty cycle of said RF signal;

said amplitude and duty cycle setting means forming said modulated RF signal.

20. The electromagnetic delivery system of claim 19, wherein said amplitude and said duty cycle are set according to test data.

21. The electromagnetic delivery system of claim 20, additionally comprising sensor means for measuring electromagnetic energy in the solution; said sensor means coupled to said amplitude and duty cycle setting means to determine said amplitude and duty cycle of said RF signal.

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22. Apparatus for delivering electromagnetic energy into a solution, comprising:
a voltage probe assembly comprising:
a first hollow-non-conductive housing defining a first water-tight chamber;
a conductive probe centrally contained within said first chamber; and
a fluid essentially surrounding said conductive probe within said first chamber;
means for generating an RF-modulated signal;
and
means for coupling said RF-modulated signal to said voltage probe assembly.

23. The apparatus of claim 22, additionally comprising a second tubular housing having closed ends defining a second water-tight chamber wherein said voltage probe assembly and said RF-modulated signal generation means are contained within said second housing.

24. The apparatus of claim 23, wherein said RF-modulated signal generation means comprises:
a helical coil having first and second ends and a central tap; and
an RF generator coupled to said first end of said helical coil and said central tap wherein said voltage probe assembly is coupled to said second end of said helical coil.

25. The apparatus of claim 24, wherein said second water-tight chamber is essentially divided into three sections, a first non-conductive section surrounding said voltage probe assembly, a second non-conductive section essentially surrounding said RF generator; and a third conductive section essentially surrounding said helical coil.

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29. A method for treating a solution, comprising the steps of:

applying RF-modulated energy to a first solution at a treatment station;

transporting a second solution from a process station to said treatment station;

causing said second solution to be proximate to said treated first solution to treat said second solution; and

returning said second solution back to said process station.

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30. A system for treating a solution, comprising:
a delivery apparatus for delivering RF-modulated energy into a primary solution to treat said solution;
a treatment station containing said delivery apparatus;

a process station containing a secondary solution to be treated by said system; and

a closed loop pipe apparatus for recirculating said treated primary solution, isolated from said secondary solution, between said treatment station and said process station; said closed loop pipe apparatus having a first end passing proximate to said delivery apparatus and a second end passing proximate to said secondary solution within said process station and wherein said secondary solution is treated by its proximity to said treated primary solution.

31., The system of claim 30, wherein said closed loop pipe apparatus comprises:

a closed loop pipe containing said primary solution; and

a circulating pump for maintaining flow of said treated primary solution within said closed loop pipe.

32. The system of claim 30, wherein said closed loop pipe apparatus is shielded to contain secondary radiation from said treated primary solution.

33. The system of claim 30, wherein said treatment station is shielded to contain secondary radiation from said treated primary solution.

34. The system of claim 30, wherein said closed loop pipe apparatus additionally comprises a radiator within said process station for distributing said treated primary solution within said secondary solution.

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35. The system of claim 30, wherein said delivery apparatus contains an energy receiving solution treated by said apparatus; said primary solution being treated due to its proximity to said energy receiving solution.

36. The system of claim 30, additionally comprising:

drive electronics for providing said RF-modulated energy to said delivery apparatus; and

a sensor located within said secondary solution for measuring a value corresponding to the treatment of said secondary solution;

said sensor coupled to said drive electronics for modifying the amount of said RF-modulated energy provided to said delivery apparatus.

37. The system of claim 30, wherein said delivery apparatus comprises:

a voltage probe contained within a chamber filled with said primary solution; said voltage probe driven by said RF-modulated energy to treat said primary solution; and

a recirculation pipe coupled to said chamber for passing said primary solution through said chamber; said recirculation pipe coupled to said closed loop pipe apparatus for recirculating said treated primary solution.

38. The system of claim 30, wherein said process station comprises:

a process solution tank containing said secondary solution; and

a primary solution tank proximate to said process solution tank for receiving said treated primary solution from said treatment station.

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