July 8, 1969 J. F. KING, JR., ET AL 3,454,484

APPARATUS AND METHOD FOR REMOVING CONCENTRATION OF PARTICLES IN LIQUIDS

Filed Nov. 26, 1965 Sheet 1 of 2

Fig-1

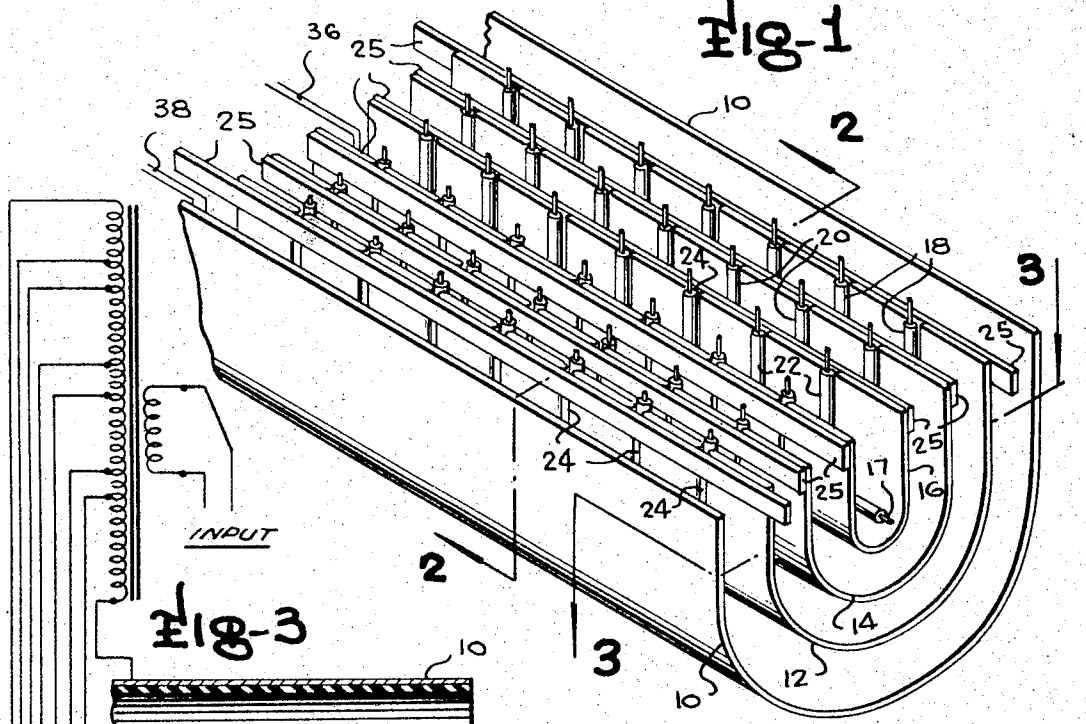


Fig-3

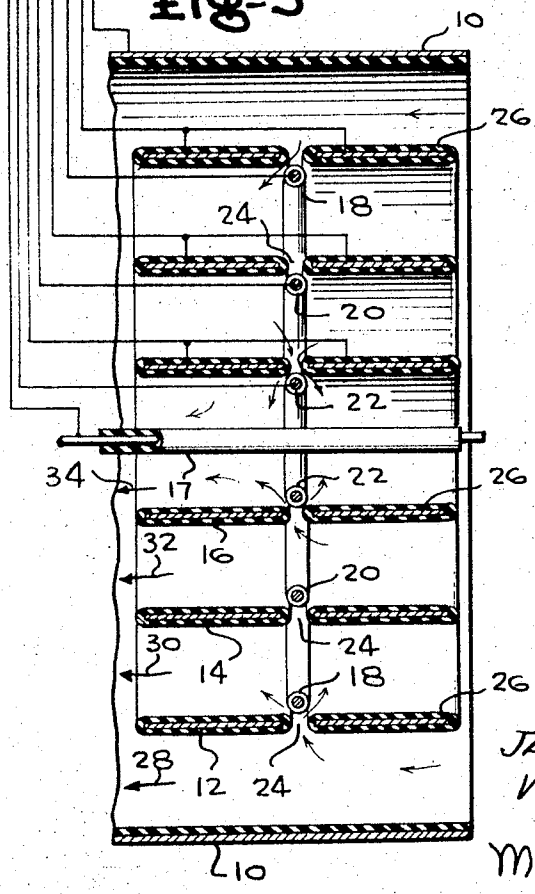
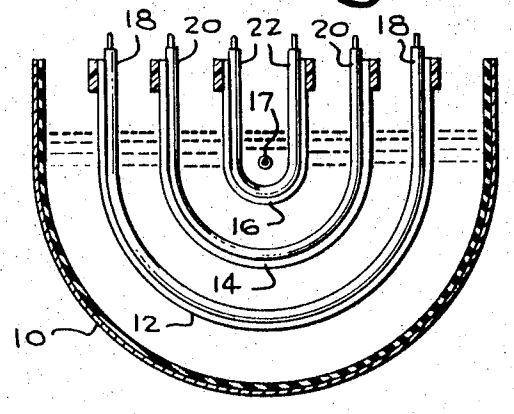


Fig-2



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Filed Nov. 26, 1965 Sheet 2 of 2

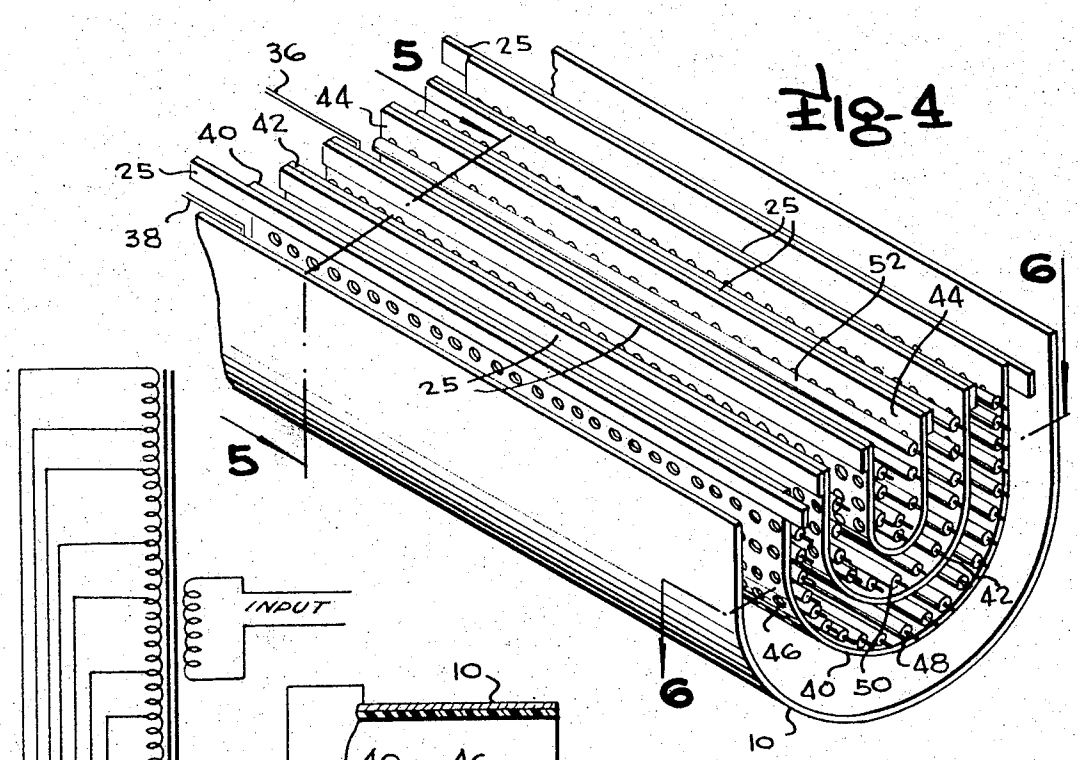


Fig-4

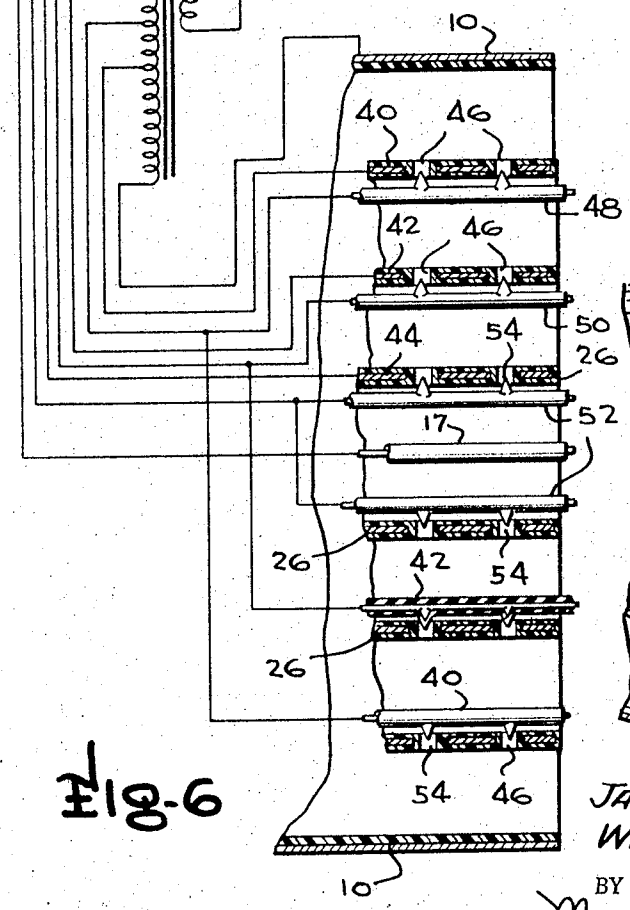


Fig-6

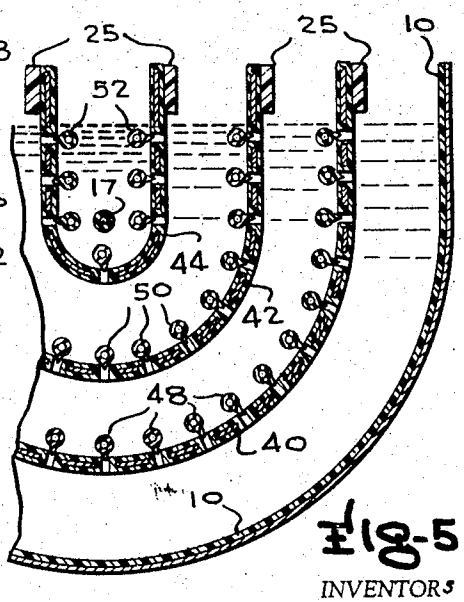


Fig-5

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3,454,484

APPARATUS AND METHOD FOR REMOVING CONCENTRATION OF PARTICLES IN LIQUIDS

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ABSTRACT OF THE DISCLOSURE

A method for removing charged particles from a liquid comprising: forming a nonuniform electric field having at least one region of relatively weak and one region of relatively strong electric field intensity, respectively, forming at least one intermediate electric field between said strong and said weak region of electric field intensity, providing a continuous moving initial stream of said liquid containing said charged particles to be removed, passing said liquid between said regions of relatively weak and strong electric field intensity, inducing the said particles in the liquid to migrate toward the region of stronger electric field intensity in selected paths through said intermediate electric field, continuously collecting separately and adjacent the respective regions of relatively weak and strong electric field intensity first and second streams of said liquid containing lesser and greater concentrations of the said charged particles, respectively.

An apparatus for removing charged particles from a liquid containing said particles comprising: an elongated conduit means for transporting liquids, an outer electrically conductive means positioned within said conduit means and providing a relatively weaker electric field intensity region along said conduit means, an inner electrically conductive means smaller in cross-section and surface area than the outer conductive means providing a relatively stronger electric field intensity region adjacent thereto, at least one intermediate conductive means between said inner and outer conductive means, each said intermediate conductive means having a plurality of openings therein to permit migration of the charged particles through said intermediate conductive means, a means providing liquid flow path between said conductive means for transporting said liquid containing charged particles to be removed, means supplying potential difference between said outer and inner electrically conductive means, a means for removing and collecting a first liquid portion richer in charged particles from the area adjacent to region of stronger field, means for collecting a second portion of said liquid having a lower concentration of said charged particles than that of the initial stream upon entering between said regions of the nonuniform electric field.

This invention relates generally to the process and apparatus for removing or collecting particles or particle clusters capable of exhibiting electrical polarization in the presence of an electric field. More specifically, the present invention relates to the method and the various configurations for an apparatus for lowering the concentration of impurities in a liquid solution, including suspensions and particularly, strong eletcrolytes in water solution, or for obtaining concentrated solutions of the desired mineral impurities, such as salts of magnesium and other metals found, for example, in sea water.

In recent years, numerous attempts have been made to remove salt from sea water in order to obtain fresh water for irrigation and human and animal consumption. Among the many processes for obtaining fresh water from sea water are those which involve freezing pure water and removing water from the solid phase of the salt solution. Another method which has been used is the hydrate method in which low molecular weight hydrocarbons combine with water to form a gas hydrate which is salt free. Another method of obtaining pure water is by solvent extraction, wherein low molecular weight organic compounds having electronegative atoms dissolve salt free water which is then capable of being released upon an increase in temperature. A further method of obtaining pure water from sea water is the use of any one of a variety of distillation processes. Humidification processes, wherein water vapor is absorbed by dry air and then released by condensation on a cooler surface, have also been considered by the art. Finally, there are numerous processes utilizing a membrane which is ion selective, and therefore either removes the salt from the saline water or the water from the salt through the use of the membrane. Included in this broad group is electrodialysis, which utilizes an electromotive force applied to a cell consisting of electrodes and an ion selective membrane.

All these processes, many of which have been refined, still depart substantially from the ideal process in that the processes are either too slow and/or the final water cost is higher than that which would meet commercial acceptability. Also the subject of the recovery of minerals from sea water has been discussed for some time. In fact, it is well known that in the case of magnesium, mineral recovery from sea water has been a great economic success for many years. This general subject has recently assumed new importance as a possible means of reducing the cost of saline water conversion. Proposals of this type have ranged from the recovery of gold to the production of fertilizer.

Accordingly, it is the primary object of the present invention to provide a process and apparatus for the rapid and inexpensive removal of matter from a liquid and more specifically the removal of particles, or particle clusters, capable of exhibiting electrical polarization distinct from that of the liquid containing such particles.

Another and more particular object of the present invention is the efficient and relatively inexpensive removal of salts such as sodium chloride from sea water to produce relatively pure water, or alternately the concentration of desired mineral solutions.

Another object of the present invention is the means and method for the transport of charged or electrically polarized particles or particle clusters from a liquid to be purified through the use of an electrical field, and in particular the provision of means and method for continuously removing such particles from a liquid through the use of nonuniform electrical fields.

This invention also has as an object the provision of the means and method for simultaneously removing substantially pure liquid in one stream and in a separate stream, liquid containing a higher concentration of particle impurities (for example, the ionic components of a salt) that would be originally contained in a fluid stream containing the particle impurities.

A further and more limited object of the present invention is the provision of independent but distinct nonuniform fields, one of which causes charged particles to move through the region between primary electrodes and the other field created by secondary electrodes which move the charged particles through openings in the primary electrodes.

These and other objects and advantages of my invention will become clear upon careful consideration of the following description read in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a perspective view partly broken away of the apparatus of the present invention;

FIGURE 2 is a cross sectional view taken along lines 2—2 of FIGURE 1;

FIGURE 3 is a cross sectional view partly broken away, taken along lines 3—3 of FIGURE 1, showing the flow paths of the electric connections to the electrodes;

FIGURE 4 is a perspective view partly broken away of another embodiment of the present invention;

FIGURE 5 is a cross sectional view partly broken away, taken along lines 5—5 of FIGURE 4; and

FIGURE 6 is a cross sectional view partly broken away, taken along lines 6—6 of FIGURE 4.

The present invention operates essentially within the broad principle of the transport of charged and/or electrically polarized particles or particle clusters under the influence of an electrical field, and in particular, plural nonuniform electric fields. The nonuniformity of the field is due to the surface area differences between the inner and outer primary electrodes and relative positioning of the electrodes, including the secondary electrodes to which a potential difference is applied. Generally, this potential difference is time-varying, which, in the simplest case, would have a periodic sinusoidal wave form or be of a conventional alternating characteristic.

The charged and/or electric polarized particle or particle clusters may be continuously collected and ultimately removed from the initial incoming stream of liquid, which in turn becomes increasingly less concentrated in the particle impurities. In one aspect of its application, according to the present invention, saline water, for instance, flows in a continuous stream in one portion of the apparatus, becoming less and less concentrated in the sodium chloride and other impurities, in order that pure fresh water can be continuously collected at the same time that the other stream flowing in another portion of the apparatus becomes more concentrated in the particle impurities. In practice, many independent stages are required to obtain the desired separation, with each stage specifically designed to work in a given range of concentration of the impurity particles.

The present invention has a broad spectrum of usage and may be stated to include the removal of any particle which is capable of obtaining an electrical charge and/or becoming electrically polarized. Of course, the particles are of such a nature that they may exhibit electric charge, including the well known compounds that permit some degree of dissociation into ions, and also including materials that may exhibit some substantial induced electric dipole moment either individually or in clusters. The term "charged particle" as hereinafter used shall be deemed to include the above, as well as those suspensions, colloids, or solutions, and the like, of all materials such as metal particles, fibers, resins, etc., which may obtain a cationic or anionic charge and/or exhibit electric polarization. In its broadest aspects, the charged particles with which the present invention is concerned are those particles or clusters of particles surrounded by a liquid medium that an electric field will influence to move in a specific predetermined direction towards the relatively stronger field.

Referring to the drawings, and particularly to the embodiment shown in FIGURES 1, 2 and 3, it is seen that the apparatus includes an elongated conduit or canal **10**, which may be open or closed at the ends and which also serves as an electrode. Positioned within the conduit **10** are a plurality of large U-shaped primary electrodes **12**, **14** and **16**, and an electrode **17** of a circular transverse cross section, which has considerably less surface area than the other primary electrodes. The electrodes may also take other shapes, as shown in the other embodiment of the invention. As shown, there are only three such U-shaped electrodes, but it must be understood that the number of such electrodes is not critical, it being important only that the innermost electrode possesses a smaller surface area than the outermost electrode. Also, there are present other small secondary electrodes **18**, **20** and **22**, each positioned adjacent openings **24**, formed by segmenting each of the large electrodes **12**, **14** and **16**, at plural transverse planes spaced along the common axis thereof. These openings are preferably approximately .05 to 2.0 cm. wide. The segments of each electrode are interconnected by channel bars **25**. These electrodes may be made of any conducting materials, such as the common metals, and coated with an insulating material **26** of good dielectric strength, such as "Teflon," nylon, PVC, etc. It can be advantageous, however, to leave the innermost electrode **17** uncoated with the dielectric material, particularly when the liquid in contact with electrode **17** possesses substantial dielectric properties, or for certain types of particles.

When a liquid, for example, water from sea water, containing charged particles, such as sodium and chloride ions, is moved through the conduit **10**, it flows through distinct paths **28**, **30**, **32** and **34**, between the various electrodes **10**, **12**, **14**, **16** and **17**. In accordance with the present invention, successive nonuniform electric fields are created by and between the various primary electrodes **10**, **12**, **14**, **16** and **17**, and other nonuniform fields are created within the opening **24** by the various secondary electrodes **18**, **20** and **22**.

The primary nonuniform electric fields created between the primary electrodes are achieved solely by reason of the relatively smaller surface area presented by the innermost or central electrode **17** compared to the outermost electrode **10**. The smaller surface area of this electrode causes a greater field concentration in the vicinity of this electrode than the field created by any of the other primary electrodes which are larger. Accordingly, the field created between the primary electrodes **10** and **17** will be nonuniform, since it is stronger nearer the center electrode. The intermediate primary electrodes do not change the general nonuniform nature of the field. The successive potential differences applied to the primary electrodes are not critical and may even be equal for all adjacent pairs including the one containing the innermost electrode **17**, which could be considered at the higher potential; however, it is preferable that the potential is progressively greater towards the center electrode. Regardless of its potential, it is the smaller size of the central electrode which concentrates the electric field in its own environment to create the strength of field gradient from which follows the nonuniformity of field intensity that is necessary to achieve the migration of the ion clusters from the outer flow path adjacent the outer primary electrode to the inner flow path adjacent the inner electrode.

The intermediate primary electrodes **12**, **14** and **16**, which may vary in number, are interposed between the outermost electrode **10** and the innermost electrode **17**, and must be able to pass the charged particles through to the innermost flow path **34**. Accordingly, openings **24** are provided in the intermediate electrodes. In order to assure the continued movement of the charged particles through the openings **24** in the intermediate primary electrodes **12**, **14** and **16**, additional locally strong nonuniform fields are created by the secondary electrodes **18**, **20** and **22**, which are adjacent these openings and form their nonuniform fields within the confines of the openings, such that any charged particle entering any of the openings under the influence of the primary field cannot remain in the opening, but rather is drawn through the opening due to the influence of these secondary locally strong, nonuniform fields.

These two distinct nonuniform electric fields may be created by A.C. potential differences, or modulated or pulsed D.C. current with bleeder resistance connected in parallel to said electrodes and applied to the primary and to the secondary electrodes. Under the influence of these two distinct nonuniform electric fields, it has been found that the ion clusters always migrate toward the region of relatively stronger electric field.

Thus, charged particles in any one flow path will continuously migrate within the nonuniform field created by the primary electrodes towards the center or innermost electrode **17**, which has the stronger electric field. These particles under the influence of the nonuniform field created by the primary electrodes will migrate across the flow path, such as **28**, and into the opening **24**. Once in the opening **24**, the particles are propelled through the openings by the locally strong nonuniform fields within the openings created by the secondary electrodes, having a field intensity gradient in the direction towards the secondary electrode and thus in the same general direction of the over all migration induced by the primary electrodes. Once the charged particles have passed through the opening **24** and enter the flow path **30**, the same process repeats with intermediate primary electrode **14**, its aperture **24**, and adjacent secondary electrode **20**. This migration continues until the particles in the strongest electric field finally form a more concentrated flow path. Consequently, flow path **34** contains the highest concentration of the charged particles. At the same time it follows that there is a pronounced reduction in the concentration of the charged particles in the liquid continuously passing in the outer flow path about the outer electrodes of the weaker field region, and particularly flow path **28**, which contains least concentration.

The voltages applied to the large electrodes **10**, **12**, **14**, **16** and **17** are a function of the impedance of the circuit comprised by the dielectric coated electrodes and the liquid in which they are immersed. Generally—though not necessarily—the potential difference applied between the innermost electrode **17** and the outermost electrode **10** is equally divided among the total number (M) of electrodes—that is, if V is the total potential difference, the potential difference between any adjacent pair of electrodes, such as **12** and **14**, is V/M. The potential applied to the small electrodes **18**, **20**, and **22** may have a magnitude between that of its immediately adjacent large electrodes. The total potential difference between electrodes **10** and **17** should be about 1 to 20 kv.; however, the present invention can operate in a much greater range, depending upon the equipment utilized.

All of the mechanisms of the transport of the charged particles are not clearly understood. However, it is believed that the externally applied A.C. field causes a relaxation-time effect and distortion in the normally spherically symmetric ion clouds, assuming the absence of external applied fields, surrounding the charged particles in strong electrolytes [1] such that the net charged distribution exhibits on the average a strong induced dipole moment in addition to its screened coulomb pole potential.

The electric force on a charge distribution exhibiting an induced dipole moment, due to the polarization effect of an external field, is in the direction of the stronger region of electric field, while the net charge of such a distribution would experience the familiar coulomb pole interaction with the force along or opposite the direction of the field, depending upon the electrical sign of the pole contribution of the given charge distribution. Thus, the charged particles plus their ionic atmospheres constitute deformable charged clusters or charged distributions that will undergo screened coulomb pole interaction with the externally applied A.C. electric field. Such charge distributions will on the average not be displaced because of the screened coulomb pole interaction with the applied A.C. field. However, this induced dipole interaction will cause the charged particles to migrate to the region of relatively stronger electric intensity. Further, the migration of these charged particles will be such that they are not retained by the electrodes **10** and **17**, or those intermediate between these electrodes, because the charged

[1] This view is in accord with the successful theory of the electrical conductivity of strong electrolytes founded by Debye and Hückel (Phys. Z. 24, 185 (1923) and further developed by Onsager (Phys. Z. 28, 277 (1927) and Onsager and Fuuss (J. Phys. Chem. 36, 2689 (1932); 61, 668 (1957).

particles will pass through the openings **24** in the electrodes under the influence of the local nonuniform fields produced, adjacent to these openings, by the electrodes **18**, **20**, and **22**. These intermediate electrodes **12**, **14** and **16** play two particularly important roles: (1) They provide, in conjunction with the multitapped transformer supplying A.C. current to them, considerable control over the radial dependence of the potential gradient, such that stronger fields can be obtained in the central region of the conduit, and (2) they provide barriers that tend to maintain the different concentrations of the solutions flowing in the various flow paths bounded by them. It is desirable in practice to maintain lamina flow as nearly as possible in all parts of the conduit, in order to prevent undesirable side currents or tubulence which would tend to produce mixing of the different concentration regions, and perhaps adversely affect the desired particle migration.

In accord with the above described mechanism of operation and the Debye-Huckel theory of conductivity in strong electrolytes, it is important to keep the frequency of the applied A.C. current considerably below that corresponding to the reciprocal of the time of relaxation of the ionic atmosphere. For example, for a 1 N solution of KCl in water at 18° C., this relaxation time t is of the order of 10^{-9} sec., where t max in general is found from the formula

$$t=\left(\frac{Z_1+Z_2}{\lambda_1+\lambda_2}\right) 15.34\times 10^{-8}/kT^2K$$

Harned and Owne, The Physical Chemistry of Electrolytic Solutions, Reinhold Publishing Co., New York (1950), page 66. In addition, the frequency must be high enough that sufficient current to operate the apparatus can be maintained at the given voltage (usually in the range of 1,000–20,000 volts). In practice, frequencies in the range of 200–5,000 cycles per second is preferred, but a range of 50–10,000 c.p.s., or greater, and having a sinusoidal wave form, could be utilized.

It is sometimes desirable to add, by well known techniques, the proper amount of inductance in series with the capacitive load of the apparatus, in order to achieve a near resonant condition which will have more efficient power transfer to the apparatus.

Bleed-off lines **36** and **38** within the inner and outer respective paths of flow remove the liquid flows more and less concentrated respectively with the charged particles. These flows may be fed successively into other but similar stages specifically designed to work at relatively higher or lower concentrations until finally the desired purity or concentration is obtained.

For sea water conversion it would be economically desirable to retain the concentration solutions of minerals (with, perhaps, the exception of the potassium and sodium chloride, which may be eliminated by well known chemical means), in addition to producing relatively pure water. Generally, the apparatus designed to produce higher concentrations will require lower voltages of 1,000 to 10,000 compared to the apparatus designed to produce relatively lower concentrations, which generally would require voltages of at least 10,000.

As an example, but by no means to be construed as a limitation on the use of the apparatus of FIGURES 1 and 2, a potential of 20,000 volts was available from a transformer, and the following potentials at frequencies of 400 c.p.s. were applied to the various electrodes, as shown:

Larger or primary electrodes	Voltage, v.
10	4,000
12	8,000
14	12,000
16	16,000
17	20,000

Small or secondary electrodes:	Voltage, v.
18	8,250–9,250
20	12,250–13,250
22	16,250–17,250

The width of the physical openings **24** between the insulating material **26** of each element making up any one of the large electrodes is 0.3 centimeter. The small electrodes **18, 20**, and **22** are approximately .05 centimeter in diameter, which makes them larger than the before-mentioned openings, so that they will not pass through the openings and are maintained in loose contact to present a minimum space through which the charged particles may migrate. The width of any electrode element between openings and in the direction of fluid flow is 5 centimeters, while the thickness of the electrode is immaterial. The large electrodes are uniformly spaced at approximately 8 centimeters distance apart. A workable apparatus having the above exemplary dimensions can be approximately 10 meters long. Electrode **17** is approximately .5–1.0 centimeter in diameter.

Water having a concentration of approximately 30,000 parts per million of NaCl passed through the apparatus at a flow rate of 3 meters per minute permits water to be recovered at the end of the flow path **28** having a concentration of approximately 29,000 parts per million of NaCl.

Another embodiment of the present invention, as shown in FIGURES 4, 5 and 6 employs a conduit **10**, which again acts as an electrode and includes intermediate primary electrodes **40, 42** and **44**. These electrodes are in the same relationship to each other and are formed in the same U-shape as electrodes **12, 14** and **16** in the embodiments of FIGURES 1, 2 and 3. As in the case of the previous embodiment, electrode **17** is positioned as the innermost electrode. Instead of the openings **24** in the form of elongated slots or spaces between axially spaced electrode segments, this embodiment incorporates the openings in the electrodes in the form of small apertures **46**, which may be in any convenient shape, such as round. The apertures or openings **46** are distributed over the surface of the electrodes and may be evenly spaced from each other. Neither the number nor arangement of these apertures is believed to be critical to the present invention, although it is desirable to have a great number of these apertures distributed throughout each of the electrodes, in order to facilitate the migration of the charged particles. The size of these openings is preferably .05 to 2.0 cm. wide. To assist the migration of the charged particles, there are provided a plurality of secondary electrodes **48, 50** and **52**, each of which is provided with projections **54** protruding slightly into each of the apertures **46**. Preferably—though not necessary—the distance from the nearest point of the projection **54** to the opening **46** should be about three times the length of the smallest dimension of the opening. The projections **54** are preferably symmetrically spaced within aperture **46**. For each aperture, therefore, there is provided a projection, in order that a local nonuniform electric field may be provided within the aperture, so as to assist the migration of the charged particles through the apertures towards the electrode producing the strongest region of electric field, which, for example, will again be electrode **17**, the innermost electrode. The charged particles migrate from the flow paths in FIGURES 4, 5 and 6, which are the same as the flow paths in FIGURES 1, 2 and 3.

The construction of this embodiment is in other respects similar to that in FIGURES 1, 2 and 3, including the coating of all electrodes with dielectric material and the application of potential.

In each of the above embodiments it should be understood that what is shown and described represents but a single stage in which may be multiple stages, each with different flow rates, potential difference, and electrode sizes and shapes, yet all within the intended scope of this invention.

From the foregoing detailed description it will be evident that there are a number of changes, adaptations, and modifications of the present invention which come within the province of those skilled in the art. However, it is intended that all such variations not departing from the spirit of the invention be considered as within the scope thereof as liimted solely by the appended claims.

We claim:

1. A method for removing charged particles from a liquid comprising: forming a nonuniform electric field having at least one region of relatively weak and one region of relatively strong electric field intensity, respectively, forming at least one intermediate electric field with intermediate electrodes between said strong and said weak region of electric field intensity, providing a continuous moving initial stream of said liquid containing said charged particles to be removed, passing said liquid across said regions of relatively weak and strong electric field intensity, inducing the said particles in the liquid to migrate toward the region of stronger electric field intensity forcing particles through said intermediate electrodes from said region of weak field intensity to said region of strong intensity in selected paths through said intermediate electric field, continuously collecting separately and adjacent the respective regions of relatively weak and strong electric field intensity first and second streams of said liquid containing lesser and greater concentrations of the said charged particles, respectively.

2. The method of claim **1**, wherein the nonuniform electric field is generated by applying time varying electric potentials to electrodes located in proximity to said stream, and including providing multiple stages wherein each stage functions in accordance with concentration of the charged particles in the liquid at the input of the particular stage.

3. The method of claim **1**, including the step of shaping the electric field into regions of relatively weak and strong intensities, each region having a vertically disposed laterally extending strata between the electrodes in a mutually parallel configuration.

4. The method of claim **1**, including providing additional nonuniform electric fields in the form of a plurality of secondary nonuniform fields acting within said primary field and along said intermediate field to drive the charged particles through said paths in said intermediate field.

5. The method of claim **4**, including the step of collecting said first and second streams in regions adjacent the regions of relatively weak and strong electric field intensities.

6. The method of claim **4**, wherein the charged particles comprise sodium and chlorine ions, and the liquid is water.

7. The method of claim **1**, including the steps of providing primary electrodes creating a primary nonuniform electric field, a plurality of secondary nonuniform fields adjacent said paths through said intermediate fields, and inducing the movement of said charged particles through said primary field and through said paths in said intermediate field.

8. An apparatus for removing charged particles from a liquid containing said particles comprising: an elongated conduit means for transporting liquids, an outer electrically conductive means positioned within said conduit means and providing a relatively weaker electric field intensity region along said conduit means, an inner electrically conductive means smaller in cross-section and surface area than the outer conductive means providing a relatively stronger electric field intensity region adjacent thereto, at least one intermediate conductive means between said inner and outer conductive means, each said intermediate conductive means having a plurality of openings therein to permit migration of the charged particles through said intermediate conductive means, driving means separate from said inner and outer means for driving said particles through said intermediate conductive means, a

means providing liquid flow path between said conductive means for transporting said liquid containing charged particles to be removed, means supplying potential difference between said outer and inner electrically conductive means, a means for removing and collecting a first liquid portion richer in charged particles from the area adjacent to region of stronger field, means for collecting a second portion of said liquid having a lower concentration of said charged particles than that of the initial stream upon entering between said regions of the nonuniform electric field.

9. The apparatus of claim **8**, including said driving means adjacent said intermediate conductive means to establish a greater nonuniform field in the area of said openings.

10. The apparatus of claim **8**, including multiple stages wherein each stage functions in accordance with concentration with the charged particles in the liquid at the input of the particular stage.

11. The apparatus of claim **8**, including means for forcing the charged particles through said spaced openings, said last named means including a plurality of locally strong nonuniform fields in regions within said openings and being positioned on the intermediate conductive means proximate to the highest primary field intensity.

12. The apparatus of claim **11**, wherein said intermediate conductive means acts as a permeable barrier that tends to block the return flow of the fluid of relatively higher concentration and such that they provide an important control of the radial potential gradients in the various channels of flow established.

13. A multistage apparatus for removing charged particles from a liquid containing said particles comprising: a first stage having an elongated conduit means for transporting liquids, an outer electrically conductive means positioned within said conduit means and providing a relatively weaker electric field intensity region along said conduit means, an inner electrically conductive means smaller in cross-section and surface area than the outer conductive means providing a relatively stronger electric field intensity region adjacent thereto, a means providing liquid flow path between said conductive means for transporting said liquid containing charged particles to be removed, means supplying potential difference between said outer and inner electrically conductive means, a means for removing and collecting a first liquid portion richer in charged particles from the area adjacent to region of stronger field, means for collecting a second portion of said liquid having a lower concentration of said charged particles than that of the initial stream upon entering between said regions of the nonuniform electric field, and each succeeding stage corresponding to said first stage and being connected in series relationship with said first stage.

14. The apparatus of claim **8**, wherein the elongated conduit is tubular and said outer, intermediate, and inner conductive means are concentric tubular members with said conduit, and each includes a plurality of space openings, and means for forcing liquid and particles through said conduit.

15. The apparatus of claim **8**, wherein said outer, intermediate, and inner conductive means are coated with a nonconductive coating.

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U.S. Cl. X.R.

204—302