

Provisional Patent Application
for
Electrostatic Fluid Deionization, particularly Seawater Desalination
by
Kim E Lumbard

SUMMARY OF THE INVENTION

[P 1] This invention pertains to fluid purification, specifically with regard to the removal of ionic solutes using electrostatics. This is highly desired in several fields, in particular for the conversion of seawater into potable water for drinking and irrigation. Our primary innovations are a self-enhancing feedback cycle by keeping reject streams separate, using deionization as a first stage of water purification instead of a final stage, and preferring small scale embodiments that enhance electrostatic performance.

BENEFITS OF THE INVENTION

[P 2] The invention has several advantages over existing art:

It uses less net energy than prevailing techniques = lower cost operation

It performs well on a small scale, enabling portable units

It can be performed efficiently alone, uncombined with other industrial processes

It allows selective removal of ions, enabling production of mineral and irrigation waters

It uses no ion trapping materials, such as resins

It employs no membranes that degrade or become fouled

It has no backwash cycle and can be operated continuously

BACKGROUND OF THE INVENTION

[P 3] There is a continual worldwide need for clean water. We need potable water for drinking, as well as water for irrigation. The best kinds of water are not fresh or distilled water. Water plentiful in minerals and containing precise concentrations of ions like sodium are best for human health, as well as livestock and crops. Mineral depletion from soil is a serious problem, and is being addressed by organizations like Remineralize. Improper fluid and ion intake is the lead order problem in the rise of modern health problems.

[P 4] The demand for clean water has outstripped the supply, and virtually all accessible fresh water sources have already been tapped. The ocean provides a vast supply of water, but the ion content is too high. In particular, the sodium ion concentration (or salinity) is around 3.5%, while the optimal salinity for animal health is around 0.9%. Sodium is so crucial that the term “desalinate” is often considered equivalent to “render potable”. Thus, we are keenly interested in a method or apparatus that can convert seawater into clean water, especially water that retains its minerals while reducing ionic concentrations.

[P 5] There are four primary methods and several secondary methods used to clean water:

Filtration Straining water through particulate beds or chambers

Flash/Vacuum Heating water and then immediately condensing it, changing pressure

Osmosis Using pressure differentials to move water across semi-permeable membranes

Deionization Employing electrostatics and trapping materials to guide ions
Secondary methods include pre-filtration (removing large particulates from murky water) and sterilization (destroying microbes using UV, ozone, *et al*). Let us compare each of the primary methods, while foregoing the secondary.

[P 6] Filtration uses particulate beds as a large strainer, physically removing impurities and trapping them. Some common filtration beds are made from activated charcoal and naturally occurring zeolites; the latter are particularly good at holding positive ions. Filtration has one large advantage over most techniques: it is quite cheap. Gravity fed systems require little energy, but operate very slowly. Chamber-based systems regulate flow through them but are still limited in speed. Since filtration traps the impurities, systems frequently require a *backwash cycle* where water is forced backward through the system at higher pressures to dislodge the accumulated

species. Backwash and slow speed are the main disadvantages to this technique. Related techniques like nano-filtration employ expensive membranes for laboratory quality work.

[P 7] Multi-stage flash distillation is the majority producer of clean water on the planet; estimates are in excess of 60%. It has many advantages. It produces distilled water which is perfect for industrial and medical applications, usually needs no secondary sterilization, and can be run at large volume speeds. But it has equal disadvantages. It uses the *most energy* per unit volume of all the techniques, and the distilled water often must be mixed back with feed water to produce actual potable water. Related techniques like solar distillation utilize a similar principle, but operate at much lower volumes.

[P 8] Osmotic units are the most widespread of water purifiers, mainly because they currently use the lowest net energy among all the processes. The pressure needed to move water across the membranes is proportional to the concentration of solute that can't cross the membrane; the energy used is directly tied to the pressure. That means that unlike other techniques, osmotic units require more energy the more impurities there are. Osmosis requires such high pressures that secondary energy recovery is needed to make them energy efficient. These problems, coupled with *membrane replacement*, are the main drawbacks.

[P 9] Deionization uses an applied electric field to migrate ions into desired areas. Because solutes are undergoing constant diffusion, secondary systems are then used to trap the ions. These are often membrane enclosed chambers, resins, and/or stationary phases from chromatography. Deionization offers the greatest possibility of low-energy creation of clean water, primarily because it can selectively remove ions while leaving non-ionic minerals intact. This "partial purification" comes closest to the desired final product of healthy drinking and irrigation water.

[P 10] However, deionization also has technical hurdles. In a strong enough electric field, the electrons of nearby molecules form dipoles and then eventually are ripped off. Corona effects start at around 1kV and can severely damage materials, and *dielectric breakdown* occurs for most materials at around 1MV. That sets the practical upper limit of voltage for our devices. Ions in an electric field also form double layers (essentially fluid dipoles), but this is a benefit for our application as it tends to aggregate ionic species.

[P 11] Let us more precisely rank each of our techniques. Seawater typically contains about

20,000-40,000 ppm (mg/l) of total dissolved solids (TDS), with sodium chloride typically forming about 75% or more of the total solids content. Here are some energy expenditures per unit volume:

kWh / kgal	Process
2.9	Theoretical limit for complete distillation of seawater
2.5	Partial deionization
4.5	Partial filtration
7-9	Combined reverse osmosis, deionization, and energy recovery system
7-14	Complete osmosis systems including energy recovery
15	Complete flash system including energy recovery
19	Just reverse osmosis
23-27	Just flash

To convert to metric, multiply values by 0.95 to get **MJ / m³**.

[P 12] There are three salient points to draw from our chart. First, none of the techniques except deionization and filtration come anywhere close to the theoretical distillation limit. However, whereas it is difficult to make filtration is solute selective, electrostatic deionization removes precisely the species we wish while leaving the others untouched. Second, most real practical systems are combined with industrial processes to enhance their net efficiency. Flash water purification systems are merged with thermal power generation plants, and osmosis facilities are merged with industrial plants requiring high pressure. This means that water purification is often entwined with some other industrial process, with the concomitant hassle. Third, even for just water purification, the reigning energy efficiency design is multi-technique (the reverse osmosis, deionization, and energy recovery system).

[P 13] Lastly, there are many other consideration factors to building a water purification facility. Some like initial and maintenance costs, corrosion, pH, scale, lifetime operation, water reject percentage and concentration, and marketable embodiments are considered within the patent scope. Others concerns like conservation, ecology, politics, *et al* are beyond our current scope. In addition, there are other applications of this technology besides seawater desalination, which we also forego addressing at this provisional stage.

SELECTED PRIOR ART

#	Patent No.	Patent Name
1	US 7,744,760	Method and apparatus for desalination
2	US 4,941,330	Multi-stage flash evaporator
3	US 6,537,456	Method and apparatus for high efficiency reverse osmosis operation
4	US 6,824,662	Electrodeionization apparatus and method
5	US 7,470,366	Water purification system and method using reverse osmosis reject stream in an electrodeionization unit
6	US 1,952,281	Method and apparatus for obtaining from alpha fluid under pressure two currents of fluids at different temperatures

[P 14] #1 is an excellent gateway patent that cites many relevant patents. In addition, it is well written with a wealth of useful calculations.

[P 15] #2 is a basic multi-stage flash distillery by William R Williamson, who published several designs over a couple decades. The Saudis have combined these with cogeneration to make sophisticated modern water purification and power plants. Arabic desalination accounts for the lion's share of worldwide efforts.

[P 16] #3 is a reverse osmosis patent that has an excellent schematic for a real world apparatus.

[P 17] #4 is a typical deionization patent that employs both membranes and resins.

[P 18] #5 is a combined system for producing highly pure water.

[P 19] #6 is the Ranque-Hilsch tube original patent.

[P 20] I couldn't find a patent for the Lord Kelvin Thunderstorm, so we refer to Wikipedia instead: http://en.wikipedia.org/wiki/Kelvin_water_dropper.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG Brief Description

- FIG. 1 A basic conceptual schematic of an electrostatic deionizer
- FIG. 2 A major enhancement creating feedback akin to Lord Kelvin's Thunderstorm
- FIG. 3 A capacitor embodiment, as a single unit
- FIG. 4 A capacitor embodiment, as multiple units in parallel
- FIG. 5 A capacitor embodiment, as multiple units in serial (and parallel)
- FIG. 6 A tube embodiment, as a single unit
- FIG. 7 A tube embodiment, as multiple units in parallel

DETAILED DESCRIPTION OF THE DRAWINGS

[P 21] FIG. 1 is a basic conceptual schematic, which has the following parts:

[P 22] **1d** is an entire deionizer, either embodied as a single unit or multiple subunits.

[P 23] **1f** is feed flow to the deionizer **1d**. We assume the feed flow has had any pre-filtration performed on it to eliminate gross particulate matter.

[P 24] **1v** is a voltage potential applied to the deionizer **1d**. Voltage potential must be between two elements, one with a negative charge **1v-** and another with a positive charge **1v+**. For the most efficient operation, ground potential should lie midway between the voltage on **1v-** and **1v+**. The voltage potential **1v** will usually not exceed 1MV. In an ideal situation, the potential would require an initial expenditure of energy and then no further energy; real practical systems will always have a bleed of electrons during operation which is small compared to the initial charging.

[P 25] **1e** is exit flow from the deionizer **1d**. Exit flow has a lower concentration of ionic solutes than the feed flow **1f**. Exit flow may be the final product, fed into another deionizer unit, or further processed in some other fashion like UV sterilization.

[P 26] **1a** is anion flow from the deionizer **1d**. Anion flow has a higher concentration of negative ions than the feed flow **1f**; it may or may not also have a higher concentration of positive ions. It typically has the same concentration of non-ionic solutes.

[P 27] **1c** is cation flow from the deionizer **1d**. Cation flow has a higher concentration of positive ions than the feed flow **1f**; it may or may not also have a higher concentration of negative

ions. It typically has the same concentration of non-ionic solutes.

[P 28] Collectively, **1f** and **1v** are considered *inputs* to the deionizer **1d**, while **1e**, **1a**, and **1c** are considered *outputs*. **1e** is sometimes referred to as *product stream* and **1a**, and **1c** are sometimes referred to as *reject stream(s)*.

[P 29] Not pictured are common equipment such as piping, pumps, wiring, bracing, etc.

[P 30] FIG. 2 is an enhanced thunderstorm schematic. It has the same parts as FIG. 1 with the additional parts:

[P 31] **1n** is negative thunderstorm feedback connection of the deionizer **1d**. This connects the output anion flow **1a** to the input negative voltage **1v-**. As the unit operates, it creates a larger negative potential, which enhances its operation.

[P 32] **1p** is positive thunderstorm feedback connection of the deionizer **1d**. This connects the output cation flow **1c** to the input positive voltage **1v+**. As the unit operates, it creates a larger positive potential, which enhances its operation.

[P 33] **1b** is a break in the feedback connections of **1n** and **1p**. It is vital that no electric circuit is formed between **1v-** and **1v+**, including a path through ionic fluid comprised of the flows **1a** and **1c**. Any break will suffice, such as forming droplets during pouring, passing through an atomizer, or ejection from a sputterer.

[P 34] **1g** is a generator from the thunderstorm effect. This produces energy from the excess voltage potential between **1v+** and **1v-**. The generator **1g** may be embodied as a direct current load, a chemical exchange battery, or otherwise.

[P 35] Collectively, **1n** and **1p** create an exponential *feedback loop* that would rapidly exceed the design limit of 1MV for the voltage potential **1v**. Thus, both **1b** and **1g** are essential features. The breaks **1b** prevents electrons from shorting the voltage potential **1v** via an ionic fluid circuit path, while the generator **1g** regulates electric potential by consuming the excess in a steady or cyclic fashion. Cycling may be desired to dislodge ions trapped near **1v-** or **1v+**.

[P 36] Not pictured is what the generator **1g** powers. It may contribute to the some part of the apparatus (such as pumping) or put to some other use (such as sterilization). Whatever purpose it is employed for, we consider that it reduces the net total energy needed to deionize the feed flow.

EMBODIMENTS

[P 37] We consider two embodiments of our idea, one based off a common capacitor plate configuration and another from a novel modification of a Ranque-Hilsch vortex tube. As we describe the drawings, we further expand upon practical considerations. To prevent visual confusion on the diagrams, we omit picturing the thunderstorm enhancements, even though the best embodiments include them.

[P 38] FIG. 3 is a capacitor embodiment of a single deionizer unit. It has the parts:

[P 39] **1f** is feed flow, with ions in solution depicted. The ions are assumed to be uniformly distributed on input.

[P 40] **1v-** and **1v+** are embodied as charged plates. The two plates are same size and orientation, typically kept a constant distance apart with aligned normal vectors. The drawing is looking down a separation gap between the plates. The plates are made of a highly conductive material covered by an insulative material, chosen especially for its resistance to corona effects. The conductor and the insulator may be sealed to one another to remove any air trapped between them. The plates do not contact any fluid, unlike common anode and cathode applications in batteries. Hence we do not refer to the plates as anode or cathode.

[P 41] **1e** is exit flow, depicted with less ions than the feed flow **1f**.

[P 42] **1a** and **1c** and anion and cation flow, depicted with greater ion concentration than the feed flow **1f**. Both reject streams are kept separate from one another and the exit flow **1e**.

[P 43] **2** are containment walls of all the flows. These alternately take the form of flat sheets, pipes, or other geometry as needed. The walls are of a non-conductive material that is highly permeable by electric fields. This minimizes dipole formation and thus interference with the electrostatics. The walls must also be stable enough to withstand the structural forces of carrying fluid, possibly under pressure. Plastic-based materials like PVC fit all these requirements, and are also in common use as piping.

[P 44] **3** are a Faraday shield. It dampens the electric field generated by **1v-** from inhibiting the cation flow **1c**, and similarly **1v+** from the anion flow **1a**. **3** is constructed similarly to the charged plates: a conductive material covered by an insulator. Unlike the charged plates **1v-** and **1v+**, **3** is

not connected to any electric circuit.

[P 45] **2** is in contact with all flows but not with the charged plates **1v-** and **1v+**. **3** is suspended by thin non-conductive strands to minimize any charge accumulation. In preferable embodiments, **2** is also connected to ground by a number of small, thin flanges protected by additional insulation. These thin strands and thin flanges are to minimize electron conduction, utilizing both material and geometric inhibition.

[P 46] In the best embodiments, the separation gap between the charged plates **1v-** and **1v+** is small. Small is defined as less than 1m, preferably less than 10cm. There are two compelling reasons to prefer smaller embodiments. First, electrostatic forces are governed by a well known $\frac{1}{r^2}$ force law. Thus, the electric field next to the charged plates is much higher than farther away. Second, analysis of the Nerst equation means that we must overcome diffusive drift; this, combined with the flow vector, gives a resultant movement of ions in the gap. The smaller the gap, the faster the possible flow, which helps overcome ion entrapment near the charged plates.

[P 47] From an engineering efficiency perspective, the optimal unit would be made on the millimeter scale employing microfluidics and resulting in almost complete ionic separation. From an overall business perspective, there is a balance between material and fabrication cost and efficiency. Since a larger embodiment has a less per volume and per flow unit cost, there is an equi-point for each application that would determine the optimum scale that maximizes performance to price.

[P 48] FIG. 4 is a capacitor embodiment of multiple deionizer units arranged in parallel. It has the same parts as FIG. 3. Careful geometric arrangement enables the re-use of parts between deionizer units **1d**. As depicted, the charged plate **1v-** is being used by both deionizers on either side of it. This results in re-use of Faraday shields **3** and combination of cation flows **1c** from both deionizers **1d** adjacent to it. Similarly, we can imagine each charged plate being shared by deionizer units on either side of it.

[P 49] This arrangement also allows for easy combination of flows. All feed flows **1f** could originate from a single pipe with multiple Ts coming off it, and all the exit flows **1e** could be similarly collected. We could collect the anion flows **1a** and cation flows **1c** in a similar fashion, with the caveat that the two pipes would optimally be separated by maximum distance and / or

additional Faraday shields **3**. In the diagram depicted, we would have all the anion flows **1a** come up out of the page, while all the cation flows **1c** would go down into the page, with a Faraday shield **3** in the plane of the page.

[P 50] We may also eliminate the single-use plates on the ends by making the charged plates at a slight angle to one another. Then all the deionizer units **1d** would form a circle, each one like a wedge of pie.

[P 51] FIG. 5 is a capacitor embodiment of multiple deionizer units arranged in series and in parallel. It has the same parts as FIG. 4. Both the left and right diagrams depict two parallel arrangements as from FIG. 4 arranged serially. In both diagrams, the exit flows **1e** from one row of parallel deionizers become the feed flows **1f** of a next row.

[P 52] The left diagram is an *alternating serial* arrangement. The anion flows **1a** from the first row are physically adjacent to the charged plates **1v-** in the next row. Similarly the cation flows **1c** from the first row contact the charged plates **1v+** in the next row (not depicted). This means a single ion will make a zig zag through the unit until being captured by a reject stream.

[P 53] The right diagram is a *direct serial* arrangement. The anion flows **1a** are diverted away from the apparatus, as are the cation flows **1c** (not depicted). This means a single ion will always drift in the same direction before being captured by a reject stream.

[P 54] The preference for the alternative or direct serial arrangements depends on a number of variables. These include but are not limited to: fluid viscosity, diffusion coefficients of the ionic solutes along with their valence, scale formation and precipitants, and concentration of non-ionic solutes. For desalination of seawater, the direct serial arrangement would be preferred.

[P 55] FIG. 6 is a tube embodiment of a single deionizer unit. It is based on the Ranque-Hilsch vortex tube. The top diagram is looking axially down the length of the cylindrical tube, while the bottom diagram is a slight perspective view from the side. It has the parts:

[P 56] **1c** is cation flow. It is drawn from an *outer ring* on one end of the tube only. This outer ring rotates counter-clockwise and downward as depicted in the top diagram, and exits to the right in the bottom diagram.

[P 57] **1a** is anion flow. It is drawn from an *inner ring* on one end of the tube only, and must be the end opposite the cation flow **1c**. This inner ring rotates clockwise and upward as depicted in

the top diagram, and exits to the left in the bottom diagram.

[P 58] **1e** is exit flow. It is drawn from a *middle ring* near the center of the tube. This middle ring has turbulence as depicted in the top diagram, and exits in the middle in the bottom diagram.

[P 59] **1f** is feed flow. The feed flow **1f** is injected tangentially at one end of the tube, which is the same end from which the anion flow is removed. There typically are multiple entry feeds, each under the same pressure. This creates the same rotation in the outer ring as fluid moves toward the cation flow **1c**, and an opposite rotation as fluid moves back in the inner ring toward the anion flow **1a**. This also creates a temperature difference between the anion flow **1a** and cation flow **1c**, which grows as we increase input pressure.

[P 60] **1v-** is a negative potential. This is in the shape of a conductive cylinder covered by an insulator. It is separated from fluid by the containment wall **2** as in FIG. 3 (not depicted).

[P 61] **1v+** is a positive potential. This is in the shape of a conductive thin rod covered by an insulator. It is separated from fluid by the containment wall **2** as in FIG. 3 (not depicted).

[P 62] FIG. 7 is a capacitor embodiment of multiple deionizer units arranged in parallel. It has the same parts as FIG. 6. The tube embodiment does not lend itself to re-use of parts, but geometric arrangement does permit easy combination of flows, as depicted.

[P 63] A tube embodiment may be preferred for several reasons. If there is a large disparity of size between the anion solutes and cation solutes, then the centrifuge effect of the tube will contribute to their separation. If solubility of a particularly difficult ion to separate is affected by temperature, then the thermal separation can enhance effectiveness.

[P 64] Currently, deionization is considered to be a final step of water purification, especially in the creation of ultrapure species. This is an outgrowth of its heritage from liquid chromatography. Deionization can be profitably employed as the first stage, which has two benefits. First, any subsequent reverse osmosis could operate at a lower pressure, since by that point there will be lower TDS. Second, the pressure from a tube embodiment could be directly re-used by an osmosis system, before finally being reclaimed by an energy generation unit. Altogether, placing the deionizer first reduces overall energy expenditure.

[P 65] The tube embodiment also offers a simple, portable deionization unit that could be used to create irrigation or drinking water on the spot.

DRAWINGS

Title of Invention:
Name of Inventor:
Mobile Number:
E-Mail:

Electrostatic Fluid Deionization, particularly Seawater Desalination
Kim E Lumbar
(626) 429-4492
kel@alumni.caltech.edu

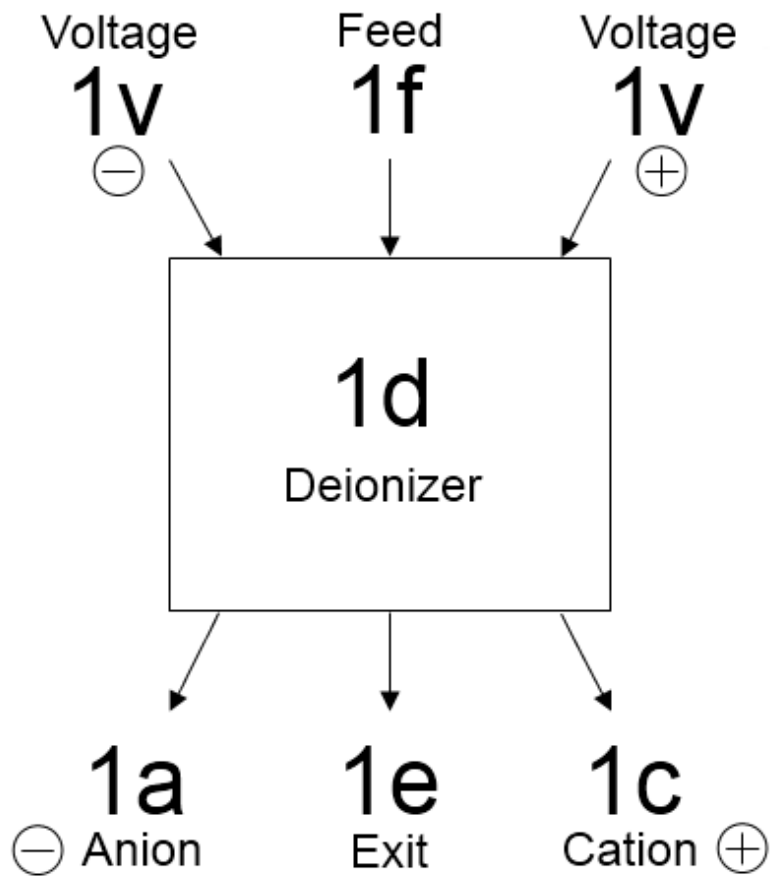


FIG. 1 — Basic Conceptual Schematic

Title of Invention:
Name of Inventor:
Mobile Number:
E-Mail:

Electrostatic Fluid Deionization, particularly Seawater Desalination
Kim E Lumbard
(626) 429-4492
kel@alumni.caltech.edu

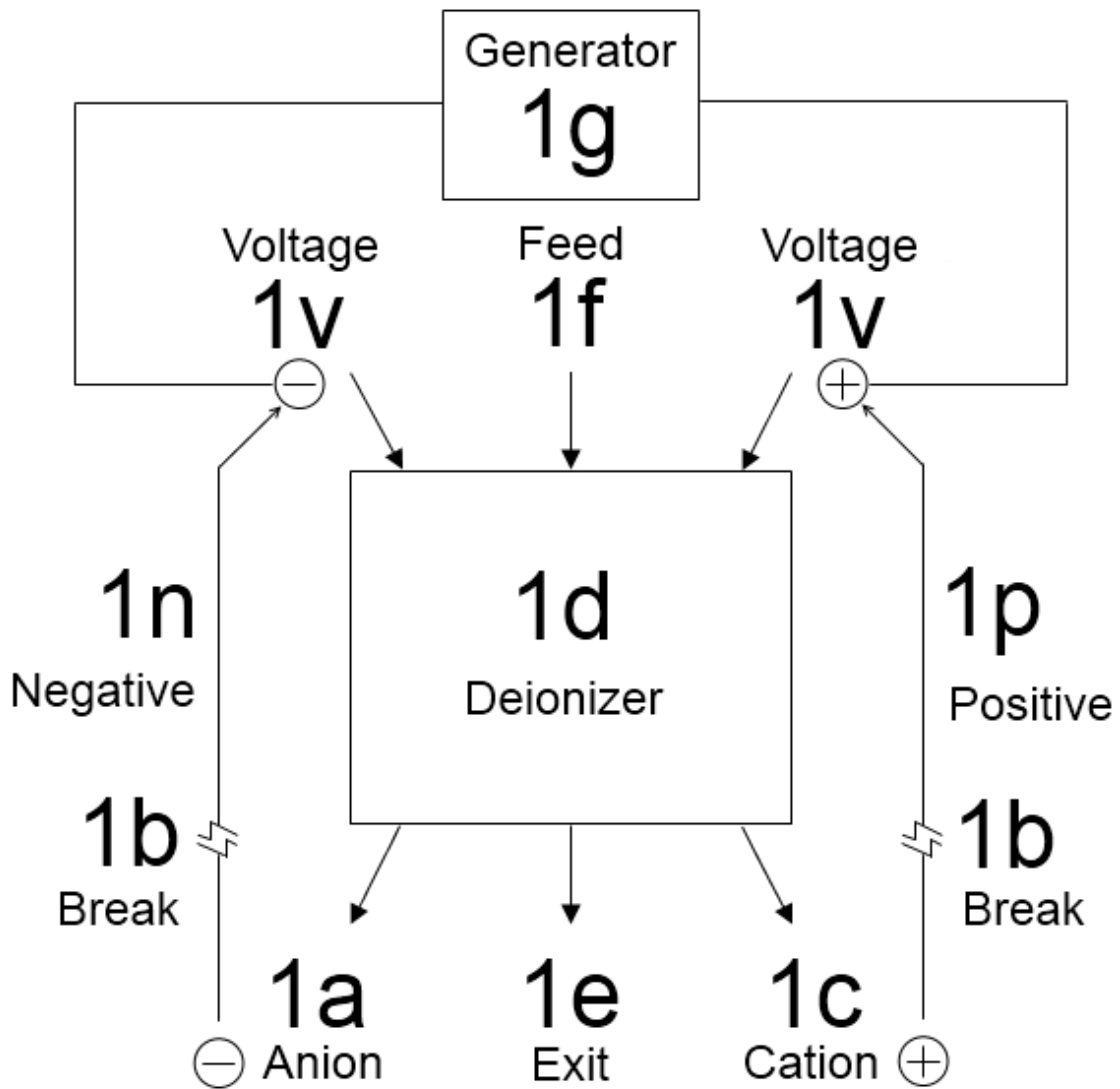


FIG. 2 — Conceptual Thunderstorm Schematic

Title of Invention:
Name of Inventor:
Mobile Number:
E-Mail:

Electrostatic Fluid Deionization, particularly Seawater Desalination

Kim E Lumbard

(626) 429-4492

kel@alumna.caltech.edu

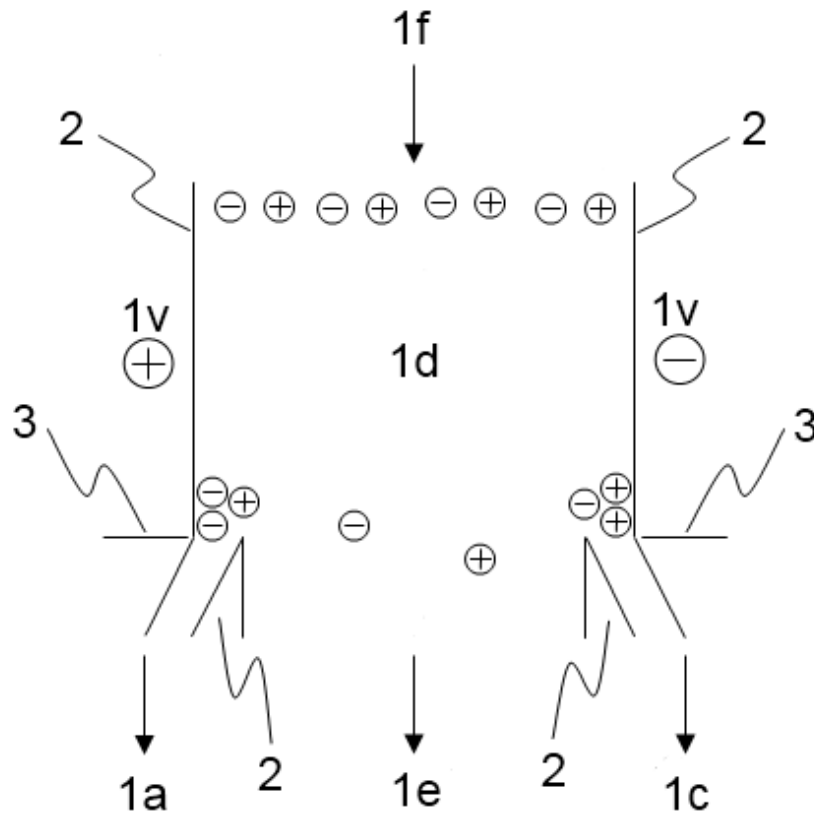


FIG. 3 — Capacitor Embodiment - Single

Title of Invention:
Name of Inventor:
Mobile Number:
E-Mail:

Electrostatic Fluid Deionization, particularly Seawater Desalination

Kim E Lumbard
(626) 429-4492
kel@alumna.caltech.edu

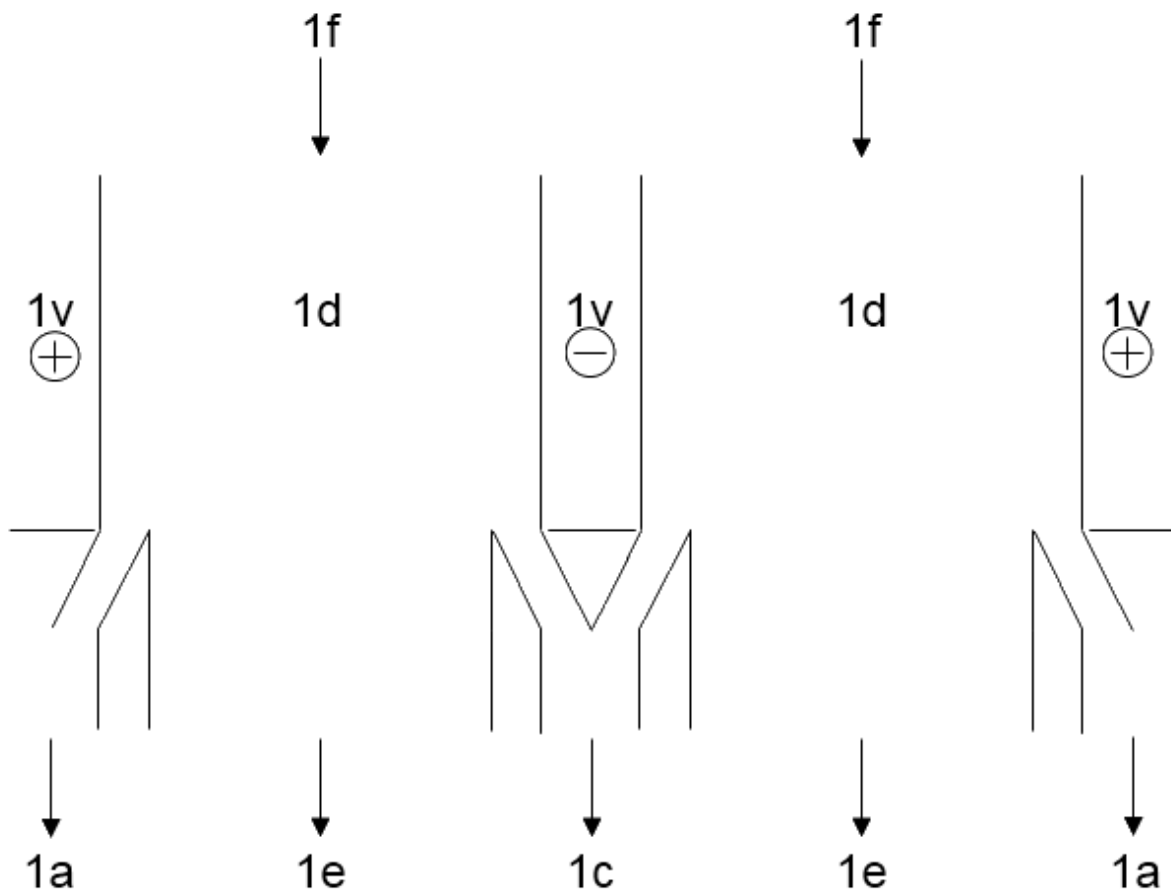
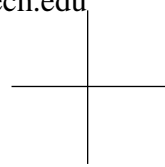
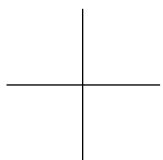


FIG. 4 — Capacitor Embodiment - Parallel



Title of Invention:
Name of Inventor:
Mobile Number:
E-Mail:

Electrostatic Fluid Deionization, particularly Seawater Desalination

Kim E Lumbard

(626) 429-4492

kel@alumna.caltech.edu

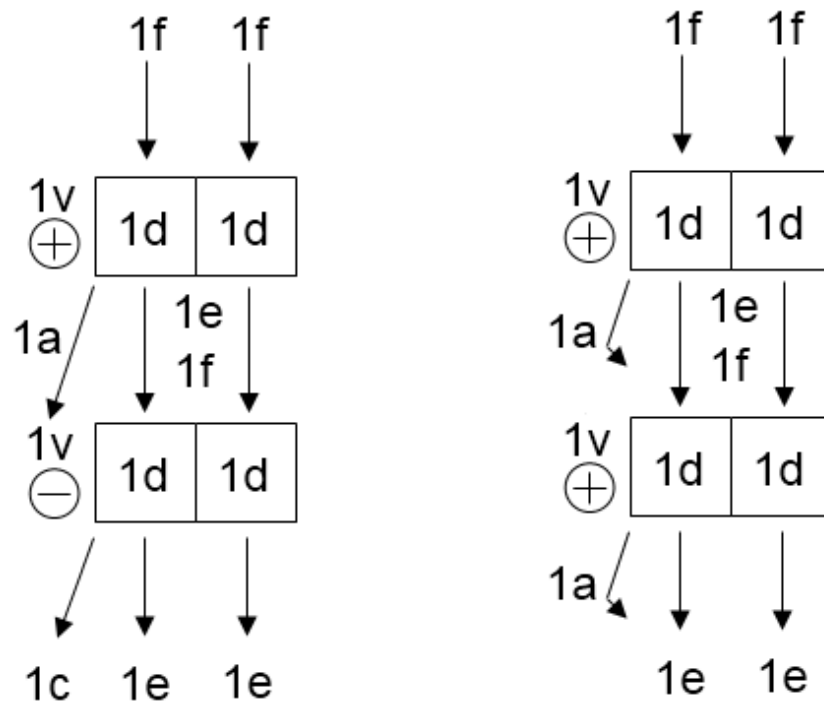


FIG. 5 — Capacitor Embodiment - Serial

Title of Invention:
Name of Inventor:
Mobile Number:
E-Mail:

Electrostatic Fluid Deionization, particularly Seawater Desalination
Kim E Lumbard
(626) 429-4492
kel@alumni.caltech.edu

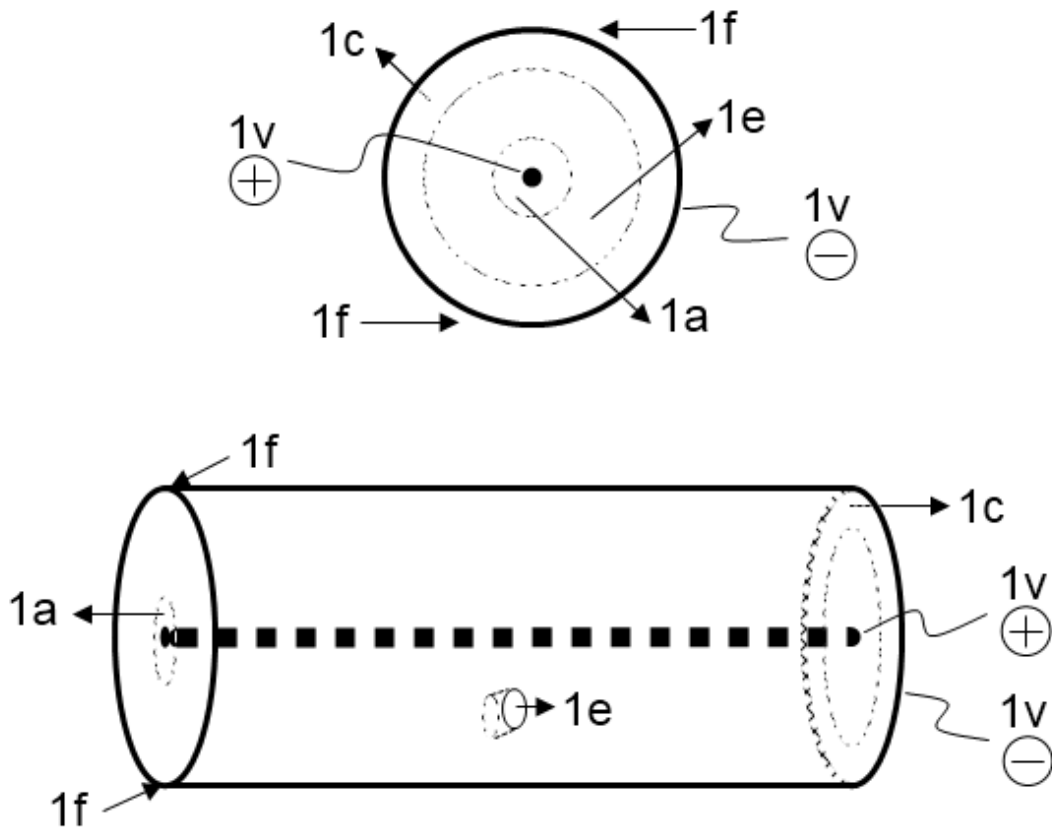
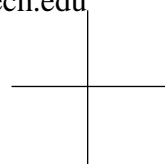
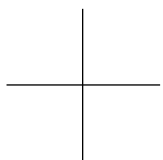


FIG. 6 — Tube Embodiment - Single



Title of Invention:
Name of Inventor:
Mobile Number:
E-Mail:

Electrostatic Fluid Deionization, particularly Seawater Desalination
Kim E Lumbard
(626) 429-4492
kel@alumni.caltech.edu

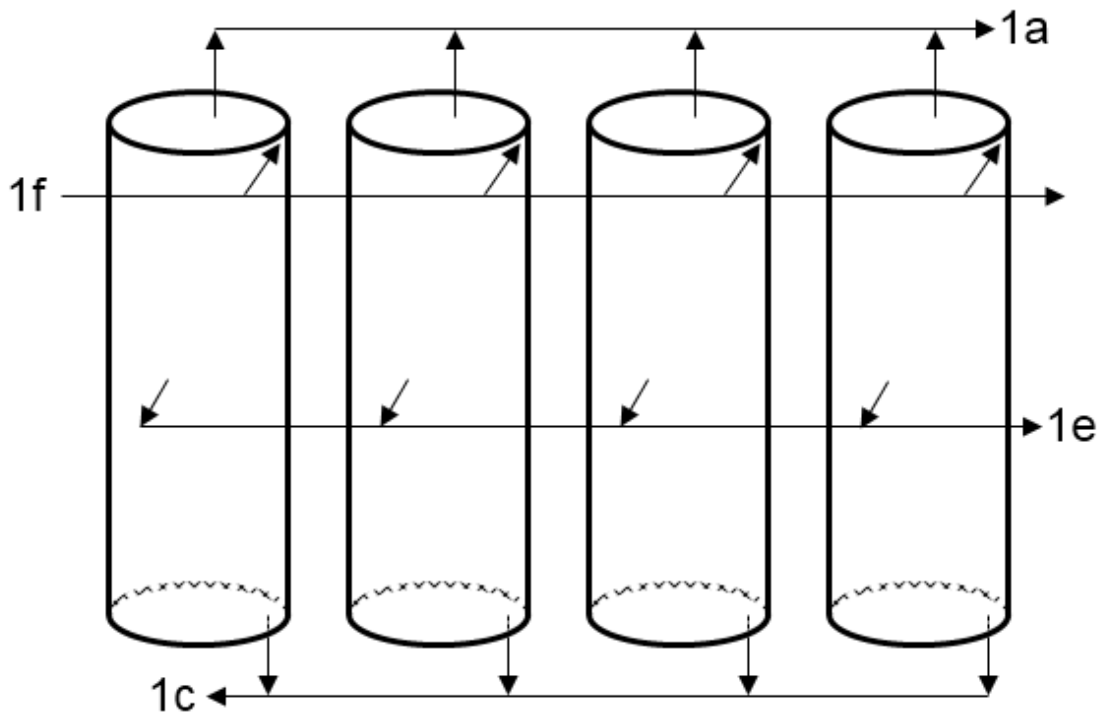


FIG. 7 — Tube Embodiment - Parallel