

Abstract: The present invention relates generally to the field of electrochemical water treatment system, and more particularly to electrochemical water treatment systems containing a power control for an electrically powered water treatment apparatus. The power control includes a master power supply unit having a control input, a slave power supply unit having a control input, a PLC having inputs from a current sensor and a voltage sensor and outputs for said master and slave power supply units. Said current O sensor is adapted to measure the electrical current flowing through the cells of the treatment apparatus, said voltage sensor is adapted to measure the voltage applied to the cells of the treatment apparatus, and said PLC is programmed so as to be able to maximize the electrical power applied to the cells without overheating.

Energy supply for waste water regeneration

POWER CONTROL FOR AN ELECTRICALLY POWERED WATER TREATMENT APPARATUS

Brief description of the drawings

Fig. 1 is a schematic representation of the motion of streams of impure water and their synchronization.

Fig. 2 is a schematic cross-section view of a W2W electrochemical reactor body of the present invention.

Fig. 2' is a slight revision of Fig. 2.

Fig. 3 is a perspective schematic sectional view of a W2W electrochemical reactor body of the present invention.

Fig. 3' is a slight revision of Fig. 3.

Fig. 4 is a perspective view of a W2W electrochemical reactor with two electrode cell cassettes and the associated electrodes.

Fig. 5 is an exploded view of one embodiment of electrode cell cassette and the associate electrodes of the present invention.

Fig. 6 shows the self-sealing construction of electrode cells of the present invention in two cross-section views.

Fig. 7 is a basic water flow chart of a W2W system.

Fig. 8 is a general scheme of one embodiment of a W2W system of the present invention.

Fig. 9 is a schematic cross-section view of one embodiment of a W2W electrochemical reactor of the present invention.

Fig. 10 shows an electrode cell cassette and its associated pair of oppositely charged electrodes of the present invention in three different views.

Fig. 11 is a perspective view of two electrode cell cassettes and their associated pair of oppositely charged electrodes of the present invention.

Fig. 12 is another perspective view of two electrode cell cassettes and their associated pair of oppositely charged electrodes of the present invention.

Fig. 13 is a schematic diagram showing how the water flows through electrodes of the present invention.

Fig. 14 is a general scheme of one embodiment of a W2W system with automatically controllable power supplies.

Fig. 15 is a schematic diagram of the automatically controllable power supplies in Fig. 14.

Fig. 16 is a schematic diagram of power supplies connected in series and their 10 connections to a PLC.

Fig. 17 is another schematic diagram of power supplies connected in series.

Fig. 18 is a schematic diagram of power supplies connected in parallel and their connections to a PLC.

Fig. 19 is another schematic diagram of power supplies connected in parallel.

Fig. 20 is a schematic diagram of power supplies connected in pseudo parallel and their connections to a PLC.

Fig. 21 is a schematic diagram of a control board interface of the present invention.

Fig. 22 is a schematic diagram of a W2W system of the present invention.

Fig. 23 is a schematic diagram of a W2W system with a water sampling plan, in which A refers to a tapping point for inspection of water included in the W2W system, B refers to a tapping point for inspection of water coming out of the reactor (katholyte), C refers to a tapping point for inspection of water coming out of the reactor (anolyte), and D refers to a tapping point for inspection of water coming out of 25 the W2W system.

Fig. 24 is a schematic diagram of a W2W system with a water flow path indicated, in which 1 refers to an electrochemical reactor, 2 refers to sedimentation containers, 3 refers to a buffer tank, and 4 refers to a preliminary tank.

Fig. 25 is a schematic diagram of a W2W system with another water sampling 30 plan, in which A refers to a tapping point for inspection of water included in the W2W system, B refers to a tapping point for inspection of water included in the reactor, C1 refers to a tapping point for inspection of water coming out of the reactor (katholyte), C2 refers to a tapping point for inspection of water coming out of the 3 filters in 50

micron and sedimentation containers, D1 refers to a tapping point for inspection of water coming out of the reactor (anolyte), D2 refers to a tapping point for inspection of water coming out of the reactor (anolyte) on an input in intermediate container after filter in 50 micron, E refers to a tapping point for inspection of water flowing through the columns with ionic-exchange resin, and F refers to a tapping 5 point for inspection of water coming out of the W2W system.

Fig. 26 is a schematic diagram of a W2W electrochemical reactor and its connections to power supplies and a mechanical filter, in which VS stands for voltage sensor, and CS stands for current sensor.

Fig. 27 is a schematic diagram showing power supplies connected in parallel 10 and electrodes connected in parallel.

Fig. 28 is a schematic diagram showing power supplies connected in parallel and electrodes connected in series.

Fig. 29 is a schematic diagram showing power supplies connected in series and electrodes connected in parallel.

Fig. 30 is a schematic diagram showing power supplies connected in series and electrodes connected in series.

Fig. 31 is a schematic diagram of one embodiment of a voltage sensor/stabilizer and its connection to a PLC.

Fig. 32 is a schematic diagram of one embodiment of a current sensor/stabilizer and its connection to a PLC.

Detailed description of the invention

The disclosure and description of the currently active Mey Rechavam PCT International Patent Application No. PCT/IL02/00911, filed Nov. 14, 2002, entitled: "WASTEWATER TREATMENT SYSTEM", taking priority from U.S. Provisional 25 Patent Application No. 60/387,585, filed June 12, 2002, is incorporated herein by reference. The cited Mey Rechavam PCT patent application illustratively describes in detail the design, construction, and implementation, of the electrochemical reactor, pre-treatment sub-systems, and post-treatment sub-

systems, without any direct or indirect description of synchronous and/or synergistic design, construction, and/or 30 operation, of the electrochemical reactor for providing stable and synchronous electrochemical process and hydrodynamic flow conditions.

The present disclosure and description of the Mey Rechavam (W2W™) invention, hereinafter, also equivalently referred to as the Mey Rechavam (W2W) invention, or as the Mey Rechavam (W2W) electrochemical reactor, or as the W2W system, or as the Mey Rechavam (W2W) water treatment/purification/regeneration system, is arranged and presented in four main parts. Part 1 is a general introduction and overall description of the W2W system. Part 2 is an illustrative detailed 5 description of the structure, function, and operation, of main and alternative embodiments, and components thereof, of the W2W system. Part 3 is a detailed description of exemplary “actual” practice and applications, and analysis of results obtained therefrom, of the W2W system. Part 4 is a detailed description of how the power control of the present invention synchronizes the power supply to a W2W 10 electrochemical reactor.

Brief Product Description

Proprietary integrated, scalable, adaptive, and modular, systems and equipment, and technical support services thereof, for treating/purifying/regenerating commercial types and quantities of impure flowable water. Based on separating and 15 removing inorganic and/or organic impurities (e.g., metals, sulfates, phosphates, oils, , and grease) from the impure water flowing through, and interacting with electrodes housed in, at least two electrode cells specially designed and constructed for providing stable and synchronous electrochemical process and hydrodynamic flow conditions. Efficient and cost effective design and operation of an energy supply 20 mechanism including a pair of synchronously connected and operative power supply units, for synchronously energizing the electrodes which oxidize and reduce components in the contacting flowing water. Generated oxidized/reduced water components complex impurities in the flowing water via mechanisms involving coagulation and precipitation, thereby forming impurity complexes removable, for 25 example, by sedimentation, from

the flowing water. Automated and computerized, including automatic process and feedback control equipment, procedures, and software.

Part 1—General Introduction and Overall Description

Following is a general introduction and overall description of the Mey Rechavam (W2W) water treatment/purification/regeneration system.

The Mey Rechavam (W2W) invention relates to the general field of water treatment/purification/regeneration, and more particularly, to a method, device, and system, for treating/purifying/regenerating commercial types and quantities of impure flowable water.

The W2W invention features a variety of synchronized and synergistically interrelated electrochemical and hydrodynamical properties, characteristics, behavior, and phenomena, which are new (non-anticipated) and inventive (not obviously derived from) prior art inventions in the field of water treatment/purification/regeneration. Structure and operation of the W2W invention, and components thereof, are designed, constructed, and implemented, using conventional engineering techniques, equipment, and materials, based on well known established physical, chemical, and associated mathematical, theories, laws, and considerations. The W2W invention corresponds to a novel and unique synchronized and synergistic model of a non-linear system, influenced by continuously occurring fluctuations of primary system parameters relating to the flowing water being treated, that is, concentration of chemical components in the flowing water and conductivity of the flowing water.

In view of the fact that the W2W invention for purifying impure flowable water must handle fluctuating conditions, it therefore includes provisions for mitigating “selective instabilities” characteristic of most ecological technologies.

This is accomplished via mechanisms of “organic” or “natural” order, which as part of the described invention for regeneration of impure flowable water, provide the capability of synchronizing and synergistically interrelating electrochemical and hydrodynamical properties, characteristics, behavior, and phenomena.

An important goal of the W2W invention is based on comprehensive and well- founded principles of synchronization and synergetics as applicable to the technology of complex processing of impure flowable water. The W2W invention addresses the task of setting up an effective, mobile, adaptive, self-sufficient device 25 (electrochemical and hydrodynamically stable reactor) as part of a larger overall system for regenerating impure flowable water. The effectiveness of the offered technical solution is due to:

- The low level of energy input required for the process.
- The low level of unproductive energy losses during a technological cycle of 30 the process.

- The possibility of combining and synchronizing at the same time certain energy-consuming autonomous technological tasks, such as electric dissolution of the anode (the electro-coagulating element) and forming at the same time a space of highly concentrated oxidizers.

- Reduction of the process duration, by precisely synchronizing the cycle time with the interaction between the technological stages of the process.

- Stabilization and synchronization of process rates, concentrations, energy inputs and time factors.

- High level of reproducibility and technical standardization of the process.

Mobility of the proposed solution is due to the following:

- Minimized construction.
- Modular construction, with fully synchronized modules.
- Flexible interaction scheme between modules, possibility of synchronized 10 change of additional processing, allowing operation of facilities during the transition time.

The proposed technical solution is adaptable in that:

- Synchronous automatic variation of the energy supply parameters of the process, upon change of conditions and initial characteristics of the process, such as 15 change of the conductivity of the aqueous solution.

- Modular, stand-alone system, made up of identical, energy-conversion

and energy-producing units, synchronously operating to supply energy for the process.

—A system of feedback sensors, supplying signals used to stabilize and synchronize the process parameters.

20 The self-sufficiency of the proposed solution consists in that there is:

—A full cycle of technological operations and transitions synchronized in all parameters among themselves, thus providing the ultimate regulation required.

—Fully autonomous system for processing various different types of sources and supplies of impure flowable water.

25 —Synchronously combining various operations in the treating/purifying/regeneration of impure flowable water so as to obtain the best possible result.

—Deriving from the process separate traditional results, such as pH corrections.

30 The main advantages offered by the W2W invention for treating/purifying/regenerating impure flowable water are due to the realization of the various fundamental characteristics of the W2W invention, and the following structural and technological advances:

—Effectively stimulating co-sedimentation (multi-sedimentation) when the impure water contains metals and other materials, enabling their sedimentation under fundamentally different conditions.

—Effective stimulation of co-sedimentation without significant change of the acidity or alkalinity of the water.

—Carrying out at the same time hydroxidation as well as electro-coagulation, without expenditure of energy and time.

—Effectively processing, via treating/purifying/regenerating, impure flowable water sources within a short space of time, permitting to speed up the operation of automatic production lines.

—Obtaining indirect data on the variation of readily-sensed parameters of operation of the system elements in treating/purifying/regenerating, impure flowable

water sources using feedback to gather information on the quality of the treated/purified/regenerated water.

- Speeding up automatic control systems.

- Speeding up flexible automated technological modules and complexes.

- Adaptation to the treatment/purification/regeneration of impure flowable water having very low conductivity, for example, 1-5 micro-Siemens.

- Achieving two-fold increase in the parameters of electric current or voltage, without additional expenditure of energy, by facilitating electrochemical processing in the system, by changing one parameter without changing the other parameter.

- Remote control of the system, along with controlling process parameters and eliminating imbalance in the electrochemical and hydrodynamic parameters of the system.

- Autonomous local shutdown of the system and remote operation, without actuating treatment/purification/regeneration of the already treated/purified/regenerated flowing water, for closed-cycle recirculation of the water.

- Rapid change of the technological regime of system operation, automatically synchronizing the operation of sources of direct electric current and the hydrodynamic part of the system with an arbitrary change in configuration, and according to the character of interaction between system components.

- Integrating the W2W invention into larger scale systems and processes, for example, reverse osmosis systems, ultra-filtration systems, etc.

Associated advantages obtainable due to specific advanced characteristics of parts of the W2W system for treating/purifying/regenerating impure flowable water:

- Indication of the presence of at least two synchronously acting sources of direct current.

- Series connection and voltage doubling relative to the maximum needed for a given conductivity of impure flowable water. A consequence of this is the increase of concentration of oxidizing and reducing agents at the output and as a result, leading to a higher percentage of hydroxides in the exiting

treated/purified/regenerated water.

—Parallel connection and doubling of the current, relative to the maximum 10 current required for a given conductivity of the impure flowable water. As a result, there is higher concentration of oxidizing and reducing agents at the output, leading to a higher quality of sedimentation of hydroxy compounds in the treated/purified/regenerated water.

—For parallel connection, there is achieving effective coagulation at high 15 current regime - up to a current density of about 4A/dm^2 , enabling dissolution of an aluminum electrode to achieve twice the effective rate of reaction, compared to conventional electro-coagulation reaction rates (current density roughly 1 to 2A/dm).

—For parallel connection, there is setting up electrolytic extraction of precious metals from the impure flowable water at the stabilization stage of hydrodynamic 20 parameters, as the water passes between the electrodes in the electrode cells of the electrochemical reactor.

—The W2W invention is applicable to treating/purifying seawater.

—There is the capability of on-line monitoring. During signal of disturbance of the synchronous regime, there is an automatic signal indicating system irregularity, followed by automatic return to the synchronous regime, along with an automatic signal informing of return to normal operating regime.

—Maintaining the quality of the treatment/purification/regeneration process output, while having a two-fold reduction in power relative to using a single energy source providing a larger power to the electrochemical reactor electrodes.

—Indication of the presence of common cathodic and anodic sections in inter electrode spaces inside the electrode cells.

—Higher intensity of the electrical field strength in the inter-electrode spaces.

—Reduced resistance to the water flowing through the inter-electrode spaces.

—Higher concentration of generated oxidizing and reducing agents.

—Prevention of the shedding or release of salts from the cathode.

- Avoidance of retention of anode scale in the anode section of the electrochemical reactor.
- Facilitated utilization of system characteristics.
- 5 —Increased service life of the electrodes, in particular, and of the electrode cells, in general.
 - Reduction of the loss of electric energy, due to the reduced resistance in inter-electrode space.
 - Asymmetric configuration of the working surfaces of the electrodes.
- 10 —Use of electrodes of varying thickness, which is important for increasing the thickness of anodes, thereby increasing electrode service life.
 - Performing electro-coagulation at the same time as performing electrooxidation and/or an electro-reduction reaction.
 - Synchronously changing the effective active surface of the electrodes, and to 15 the same extent on both cathode and anode.
 - Unhindered division, into two equal parts, of the water flowing into or out of the inter-electrode space.
 - Reduction of hydraulic resistance to the flowing water, for carrying out the process without requiring assistance of extra pressure in the inter-electrode space.
- 20 —Increasing the cross-sectional area between each pair of two electrodes, thereby increasing the rate of water flowing between the inter-electrode space, translating to increasing performance of the electrode cells, and therefore, of the electrochemical reactor.
 - Increase of cross-sectional area (theoretical input) of the electrode cells, 25 enabling higher input of water flowing through the electrode cells, and through the electrochemical reactor.
 - Increased throughput capacity of the electrode cells and of the electrochemical reactor.

According to the result of experimental studies of the system, a highly 30 significant advantage of the W2W invention is the twofold power reduction supplied

to the electrodes, compared to prior art versions of energy conservation. As a consequence thereof, there is:

- Avoidance of formation of solid salts, or scaling, at the cathode surface.
- Avoidance of passivation or deactivation of electrodes (anode and/or cathode).
- Avoidance of unmitigated or total destruction of electrodes (anode and/or cathode).
- Avoidance of overheating electrodes (anode and/or cathode).
- Reduction of size of the power sources of the electrodes (anode and/or cathode).
- Reduction of the installed power of the power sources and a lower electrical safety threshold.

The iW2W invention for regenerating aqueous solutions is designed,

constructed, and implemented, using the principle of dynamic symmetry. Dynamic symmetry is defined as “the coordination of all non-stationary system states and the stabilization of all transitions among system states possessing different energies”, as stated in the Encyclopedia of Physics, p. 683, published by the Great Russian 15 Encyclopedia, Moscow, 1999.

In general, the terms “synchronous” and “synchronization” are defined by, and refer to, actions, devices, systems, and/or processes, taking place or occurring, moving, and/or operating, at same time and/or at the same rate, for example, by having identical periods and/or phase. Moreover, the term “synchronize” is defined 20 by, and refers to, causing actions, devices, systems, and/or processes, to occur at the same time and/or at the same rate; to be simultaneous; to move and/or operate in unison.

Herein, with respect to the present invention, a special form of synchronization is used. As defined in the same Encyclopedia of Physics, p. 687, and 25 as defined and described in “Synchronization of Dynamical Systems” by I.I.

Blechman, Moscow, 1968, with particular reference to electronics applications, synchronization refers to the special situation when “the working parameters of two

direct current sources are such, that one of the sources (the synchronization master) acts on the other (the synchronized slave) by feedback regulation". For the present

30 invention, the operating regime under dynamic symmetry of states for the system consists of two direct current sources, whereby all synchronizing parameters are taken to correspond in real time to the parameters of the synchronization master source. For the present invention, for example, as illustrated in Figs. 16-20, the operating regime under dynamic symmetry of states (conditions) for the water treatment system is determined by at least two direct current sources (power supply units), whereby all synchronizing parameters are taken to correspond in real time to the parameters of the synchronization master source.

The W2W invention features integrated, scalable, adaptive, and modular, sub- 5 systems and equipment, for treating/purifying/regenerating commercial types and quantities of impure flowable water. A main aspect of the W2W invention is based on separating and removing inorganic and/or organic impurities (e.g., metals, sulfates, phosphates, oils, and grease) from the impure water flowing through, and interacting with electrodes housed in, at least two electrode cells of an electrochemical reactor 10 specially designed and constructed for providing stable and synchronous electrochemical process and hydrodynamic flow conditions. The W2W invention features efficient and cost effective design and operation of an energy supply mechanism including a pair of synchronously connected and operative power supply units, for synchronously energizing the electrodes which oxidize and reduce 15 components in the contacting flowing water. Generated oxidized/reduced water components complex impurities in the flowing water via mechanisms involving coagulation and precipitation, thereby forming impurity complexes removable, for example, by sedimentation, from the flowing water. The W2W system is fully automated and computerized, including automatic process control, feedforward 20 control, and feedback control, equipment, procedures, and software.

Operation of the specially designed and constructed electrochemical reactor is initiated and maintained by two interrelated power sources (generators) which considerably differ in power. This is due to the fact that the first regulation (calibration) of voltage is carried out on the first source (the synchronization master),

25 during which time the second source (the synchronized slave) remains in standby (starting pause). This means that the instantaneous power of the first source being calibrated will momentarily exceed the power of the second source. A detailed scientific explanation of the synchronization of two coupled systems is provided in the aforementioned cited Encyclopedia of Physics, p. 687. In this situation, the first 30 source, having an instantaneous high output power, plays the role of the

synchronizing master, while the second source which is momentarily weaker, plays the role of the synchronized slave.

After the starting calibration of the voltage of the first source, in relation to the conductivity of the flowing water during calibration, the second source starts running in an identical regime. Since both sources run in a “stabilized voltage” regime, during operation of the W2W invention, upon change of conductivity of the flowing water being treated/purified/regenerated, the master source reduces its output voltage and the second source steps up its voltage. The application of the herein defined and 5 described synchronization principle leads to a non-linear system with continuously occurring fluctuations of primary system parameters relating to the water being treated/purified/regenerated, that is, concentration of chemical components in the water and conductivity of the water, in a steady engineering regime, and provides stable operation under all energy conditions, and a general energetic balance of the 10 system for treating/purifying/regenerating an impure water source.

Part 2~Structure, Function, and Operation

The following is an illustrative detailed description of the structure, function, and operation, of main and alternative embodiments, and components

thereof, of the Mey Rechavam (W2W) water treatment/purification/regeneration system.

15 Hetero-coagulation

Installation into the water treatment/purification/regeneration electrochemical reactor of electrode cells having anodes made of aluminum or pure iron, leads to an effect whereby the basic process of generating oxidizing and reducing agents in the stream of water is complemented by anodic debris which is a coagulant. This facilitates the process associated with the necessary separation of disperse phase substances from the dispersing medium. This “coagulation threshold” rises rather rapidly. In most cases, the flowing impure water contains various salts of polyvalent metals, which are hydrolyzed to produce colloidal hydroxides. This stimulates the process of hetero-coagulation, and often basic coagulation as well. In hetero- coagulation, various disperse systems reciprocally coagulate with one another, resulting in particles of one disperse phase adhering to those of another phase. Hetero-coagulation increases upon mutual mixing of segregating salts with variously loaded particle surfaces, since ionic type of electrostatic forces among them lead to mutual attraction, and not repulsion, of the particles.

30 Brownian motion kinetics of coagulation of colloidal systems determines the needed contact time of the flowing water contacting the electrodes, and the flow through the cells in the inter-electrode space, so that the number of independent unrelated units is diminished by half, giving rise to a “coagulation threshold” contact time expressed in the following form, as described by the “Theory of Smoluchovski”,

in Chemical Encyclopedia, vol. 2, p. 817, published by the Soviet Encyclopedia, Moscow, 1990:

$$t = 3 \eta / [4 k T n_0 a],$$

where t = the time in which the number of independent unrelated units is halved;

η = viscosity of the medium; k =

Boltzmann's Constant;

T = the absolute temperature ($^{\circ}\text{K}$); n_0 = initial particle concentration;

a = the so-called coefficient of coagulation slowdown. In the absence of an energy barrier, that is, at high current densities, which for the present invention is about $4\text{A}/\text{dm}^2$, whereby $a = 1$; in the presence of an energy barrier, $a < 1$.

The time of stay in an electrode cell within the inter-electrode space in a system having a throughput of $\text{lm}^3 / \text{hour}$ is about 3 seconds. During this period of time, the entire volume of the water flowing through the electrode cell experiences the 15 action of a space-coagulating network. For a sample of water passing through the

electrode cell for approximately 0.2 - 0.6 second, after exiting from the inter-electrode space, whether from the anode or from the cathode, the volumetric weight of the water sample characterizes the initial turbidity, that is, the segregated disperse medium (precipitate). The unstructured sediment phase deposited in the course of 20 between about 1 and 2 minutes passes into the structured sedimented phase and the consolidated precipitate layer.

The candelabra (in particular, menorah) -like labyrinth configuration or shape of the electrochemical reactor used in the W2W system, provides a synchronized electrochemically active and hydrodynamically stable environment for separating 25 impurities from the flowing water. To obtain optimum conditions for hydrodynamic synchronization of all parallel streams of the flowing water, the electrochemical reactor body of the electrode cell is filled by a labyrinth in the form of a “menorah”.

This structure makes possible the following:

- Disposing the electrochemical reactor horizontally as well as vertically.
- 30 —Stabilizing the dynamic flow of all streams without additional energy expenditure.
- Synchronizing all entering streams for each of the electrode cells.
- Synchronizing the motion of parallel streams in the inter-electrode space.

The motion of streams of the impure water and their synchronization is schematically shown on Fig. 1, and the “menorah”-like labyrinth is schematically shown on Fig. 2. The flowing water is directed into two equal parallel streams,ml

and **in2** (Fig. 1). Streams **ini** and **in2** are driven by a pressure in a range of between 5 about 1.2 to 1.5 bars. As shown in Fig. 2, in electrochemical reactor **20**, channels **1** and **2** are provided with openings **3** and **4** facing towards a working chamber **5**, while openings **6** and **7** face the working chamber **8**. Working chamber **5** and working chamber **8** are joined to the channels adjacent to channels **1** and **2**, respectively. The channels of the two working chambers are interconnected by way of an opening **9**.

10 Since operation of chambers **5** and **8** proceeds in an absolutely identical, that is, synchronous, manner, it is possible to consider the hydrodynamic balance for only one of them. The flow in channel **1** comes out through opening **4** in the adjacent channel and reaches the level **AH**, whereby on account of the presence of openings **3** and **4**, this level is identical in both channels, and continues upwards to come out **15** through the channels into working chambers **5** and **8**. The difference **AH** for the two channels is the same, and is maintained in a synchronous regime, whereby opening **3** stabilizes this regime, allowing passage of air out of both channels.

In electrochemical reactor **20**, absolute working symmetry is obtained between channels **1** and **2**, and the adjacent channels (Fig. 2). Due to the presence of opening **20 9** and **AH** being symmetrical for both channels, the flow speed in the two identical parts is the same and symmetrical for all channels adjacent to one of the working chambers **5** and **8**. This symmetry permits synchronization of the flow speed at all stages of motion of the water flowing throughout the labyrinth, and thus permits synchronizing the transit time of corresponding symmetrical parts (Fig. 1). This **25** circumstance permits the electrochemical reactor to be considered as a synchronized tandem electrode cell, internally connected to provide hydrodynamic synchronization of the electrode cells. This also permits the drawing of electric energy from two synchronized power sources.

Fig. 3 is a schematic diagram illustrating a perspective view of the menorah- **30** like labyrinth configuration or shape of the electrochemical reactor **20** used in the W2W system, illustrated in Fig 2. Fig. 4 is a schematic diagram illustrating

a perspective view of the electrode cells as part of the electrochemical reactor 20 used in the W2W system.

Main Structural Characteristics of the Electrochemical Reactor

- Construction of the electrochemical reactor body labyrinth in the form of a “menorah”, as illustrated in Figs. 2 and 4.
- Hydraulic connection between adjacent channels of the labyrinth.
- Geometric and hydraulic symmetry between homologous elements of the electrochemical reactor body labyrinth.
- Provision within the electrochemical reactor body for two electrode cells, identical in all structural and technological parameters.
- Trapezoidal cross-section of the electrode cells in the case of plane-parallel 10 electrodes (as a variant) with parallel active working surfaces, for example, as illustrated in Fig. 5.
- Self-sealing construction of the electrode cells, for example, as illustrated in Fig. 6.
- Composite electrochemical reactor body.
- Other spatial position of the body (as a variant).
- Other form of the electrode cross-section (as variant).
- Co-axial tubular electrodes (as variant).
- Two independent, identical, sources of direct electric current, synchronized in all basic parameters.
- Symmetric position (as variant) of the active working surfaces in the electrode cells.
- Asymmetric position (as variant) of the active working surfaces in the electrode cells.
- Different combination of the cross-section of the inter-electrode space.
- Combined cathodic and anodic space in the cavity of the inter-electrode volume of the electrode cells (as variant).
- Communicating zones, connected by adjacent symmetrical channels in

the electrochemical reactor body labyrinth.

—Empirical relationship between the area of the communicating zones and the 30 cross-sectional area of the inter-electrode space:

$$Sc.z. \cong Si.e.s. ,$$

where Sc.z. is the area of the communicating zones, and Si..e.s. is the area of the interelectrode space.

Empirical Parameters

Area of inter-electrode space is on the order of about 600 mm². Width of the active working surface of the electrodes is on the order of about 100 mm. Area of electrode cross-section is on the order of about 200 mm . Preferred electrode 5 materials are stainless steel, titanium, aluminum, iron, or carbon-carbon.

Main Technological Characteristics of the Electrochemical Reactor

—Stabilization and even distribution of the flowing water at the input to the electrochemical reactor.

—Gravitational stabilization and synchronization of streams of aqueous 10 solution at the input to the inter-electrode space in the electrode cells.

—Synchronous passage of streams of aqueous solution through the inter-electrode space in crossing magnetic lines of force of the electric field at high voltage between active working surfaces of the electrodes.

—Current supply by two synchronized, equivalent, identical sources of direct 15 electric current, with doubling of one output parameter, current or voltage, by means of their synchronization in series or in parallel connection with hydrodynamic stabilization of the water flowing through the electrode cells.

—Simultaneous parallel action by the technique of generating oxidizing and reducing agents and the technique of electrically assisted dissolution (saturation 20 volume of coagulant ions), using a single energy supply mechanism operative with two synchronized power supplies.

-Separate output of catolyte and anolyte (as variant).

-Sedimentation in sedimentation tanks, using hydrophobic enhancers and using hydrophobic sedimentation threads, for the purpose of increasing rate of 25

sedimentation as a function of time.

Description of Operation of the W2W System

The W2W system for water treatment/purification/regeneration is applicable to industrial waste water as well as sewage. The treated/purified/regenerated water is of a quality permitting reuse in technological cycles. Water 30 treatment/purification/regeneration is performed by using an electrochemical method, whereby a direct voltage is applied across neighboring electrodes, resulting in the generation of alkalis (on the anode) and acids (on the cathode). Since water contains various pollutants and impurities, these enter into chemical reaction with the electrochemically generated alkalis and acids.

Chemical reactions taking place in flowing water immediately adjacent to the electrodes are considered as redox reactions. Electrolysis thus consists of a reduction reaction at the cathode and an oxidation reaction at the anode. A metallic anode may be (a) non-dissolving and only acting as an electron transfer site during electrolysis, or 5 (b) dissolving (active), whereby it is oxidized upon electrolysis. The redox activity of the electric current in many cases reinforces chemical oxidation and reduction reactions.

Examination of the tables of standard electrode metals shows the following:

1. Metal cations, for example, Cu^{+2} , Hg^{+2} , Ag^{+} , Pt^{+2} , and Pt^{+4} , having a 10 standard electrode potential greater than that of hydrogen, during electrolysis are completely dissolved either at and/or by the anode, and are deposited in metal form onto the cathode.
2. Metal cations, for example, Li , Na^{+} , K^{+} , and NT^{+2} , down to Al^{+3} , having a standard electrode potential less than that of hydrogen, during electrolysis, 15 remain attached to the anode without dispersing among the water molecules.

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3. Metal cations, for example, Mn , Zn , Cr , and Fe , having a standard electrode potential less than that of hydrogen, and greater than that of aluminum,

during electrolysis, deposit onto the cathode, and become dispersed among the water molecules.

20 Cations of such substances are readily dispersed around the cathode, representing high positive potential. Reactions going on at the anode depend on the physical and chemical characteristics of the electrolyte, as well as on the anode material. Products detached from the electrodes may be involved in chemical reactions among themselves.

25 In electrolysis, the quantitative relationships between the transported substance and the current passing through the electrolyte are expressed by Faraday's First and Second laws:

 First law - the quantity of substance detached from an electrode is directly proportional to the electric charge transported between the electrodes.

30 Second law - the quantity of substance detached from an electrode upon transport of one unit of electric charge is directly proportional to the chemical equivalent of the substance.

 It follows from Faraday's laws that to detach a mass G of substance equal to 1 equivalent E requires a transport across the electrodes of 96,487 coulombs of electric

charge. This constant is known as Faraday's constant. Thus, $G = EIT/96487$, where I is the current strength, T is the duration of the electrolysis.

 Typically, the electrochemical reactor of the W2W water treatment/purification/regeneration system can process contaminated water, which is fed into the electrochemical reactor, having the following physical and chemical properties, characteristics, and composition:

1. pH from about 4 up to about 10.
2. Salt content up to about 2000 mg/l.
3. Total BOD (biological oxygen demand) up to about 150 mg/l.
- 10 4. Suspended particles not larger than about 0.7 mm, in a concentration of not more than about 2 % by volume of the contaminated water fed into the electrochemical reactor.

5. Typically, according to the source, for example, a metallic plating process, of the contaminated water to be treated by the W2W system, there is a dominant

15 metallic ion contaminant, for example, copper ion in water exiting from a copper plating process. The electrochemical reactor of the W2W system can process a maximum concentration of up to about 2000 mg/l of the dominant metallic ion contaminant in the water fed into the electrochemical reactor. In cases where hexavalent chromium is the dominant metallic ion contaminant, the electrochemical

20 reactor can process a maximum concentration of up to about 100 mg/l of hexavalent chromium in the input water.

6. Separate from, or in addition to, the contaminated water including a dominant metallic ion contaminant, the electrochemical reactor of the W2W system can process water containing a 'total' concentration of up to about 100 mg/l of non-

25 ferrous metal ions, for example, zinc, copper, nickel, cadmium, trivalent chromium, as long as the concentration of any one of such non-ferrous metal ions does not exceed about 30 mg/l. In the event that the total concentration of non-ferrous metal ions is higher than about 100 mg/l in the water fed into the electrochemical reactor, there is a need for reducing the total concentration by subjecting the input water to a pre-

30 treatment process (included as part of an overall configuration of the W2W system), prior to feeding the input water into the electrochemical reactor. The particular type of pre-treatment process is selected, in part, according to the actual types and levels of contaminants in the input water.

5. In cases where the input water includes insoluble compounds, for example, salt hydroxy compounds, there is a need for decreasing the total concentration of such insoluble compounds as much as possible, for example, by using one or more pretreatment processes (included as part of an overall configuration of the W2W system),

5 prior to feeding the input water into the electrochemical reactor.

Any pre-treatment process, included as part of an overall configuration of the W2W system, used for the above indicated preliminary cleaning or pre-treatment of the input water before being fed into the electrochemical reactor is performed using reagents which are compatible with the downstream electrochemical process taking place inside the electrode cells of the electrochemical reactor. For example, reagents used in any such pre-treatment process should not influence (by increasing or decreasing) the solubility in water of the electrodes, for example, aluminum or iron electrodes, operative in the electrode cells of the electrochemical reactor.

The water treatment/purification/regeneration process does not need special reagents, and is controlled just by varying the electric parameters of the electrochemical reactor.

The facility power supply preferably consists of two sources. In case the impure water source is of high conductivity, the power sources will be connected in parallel, and in case the conductivity is low they will be connected in series. Each power source operates in a voltage stabilized regime, using negative voltage feedback. This recalls similar feedback of identical source operation under PLC (Programmable Logic Controller). An advantageous result of this solution is that no imbalance is involved at the output of the power sources, since the output current and voltage are kept identical.

The basic flow scheme of the W2W water treatment/purification/regeneration

system is illustrated in Fig. 7, along with reference to an exemplary preferred embodiment illustrated in Fig. 8. Impure flowing water enters from a supply tank by way of a valve 2, descending along a system pipeline through a mechanical filter 3 to reach the electrochemical reactor 20. The throughput is determined by means of a control output valve 4 at which an indicating output rotameter 5 is provided.

Within the electrochemical reactor 20 electrochemical processes take place, which result in the formation of certain hydroxy compounds of metals as well

as salts which exit the electrochemical reactor 20 in the form of small floccules, after two cycles of the catalite and one cycle of the analite. These cycles are characterized by reactions taking place in electrochemical reactor 20, and in electrochemical reactor outlet tanks 7 and 8 within which the floccules are built up.

From the electrochemical reactor outlet tanks 7 and 8, the flowing water is directed to the third phase of a vertical thinwalled sedimentation column 9. From 5 sedimentation column 9, the clarified water passes through a regulator level vessel 10 into a reserve vessel 11. From that vessel, a water valve 12 allows passage of the flowing water out through mechanical mesh filters 13 to ion-exchange filters 16. The throughput across ion-exchange filters 16 is determined by an output valve 14, and indicated by means of a rotameter 17.

In addition to the previous description, above, of the electrochemical reactor 20, as illustrated in Fig. 2, further details of the electrochemical reactor 6 (Fig. 8) are herein provided, with reference to Fig. 9, a schematic diagram illustrating an exemplary preferred embodiment of the electrochemical reactor 20. For consistency and clarity, electrochemical reactor components and reference numbers thereof,

shown in Fig. 9, are the same as those shown in Fig. 2.

As shown in Fig. 9, the electrochemical reactor 20 includes two working chambers 5 and 8, each with its specific two electrode cell cassettes and their associated pair of oppositely charged electrodes, as previously illustrated in Figs. 4, 5, and 6, and illustrated herein, in Figs. 10, 11, and 12, made of the same or of different materials.

In order to optimize the regime of operation of the electrochemical reactor 20, the construction represented in Fig. 9 is specially designed and implemented for allowing estimation of the effectiveness of operation of the cassettes and of the electrolytic processes according to the electrical parameters which play a major part in controlling the operating regime in the inter-electrode gap and in the cassette covers. Exemplary electrode dimensions are 100 mm x 320 mm,

and the inter-electrode gap between them is 6 mm. Accordingly, the cross-sectional area through which the water flows is $100 \times 6 = 600 \text{ mm}^2$.

To estimate the character of the flow we make the following observations:

- a. The flow temperature of the water across the gap is constant in the direction of the flow.
- b. Rate of gas evolution from the liquid is negligible.
- c. The internal electrode surface has an insignificant roughness coefficient.
- d. No water is condensed in the course of operation.

In order to determine the character of the liquid flow, we apply the criterion of the Reynolds number (Re), determined by the formula:

$Re = [\rho V D] / \eta$, (1) where ρ is the liquid density, V is the velocity of flow, D is the channel diameter, and η is the dynamic (=kinetic) viscosity.

For the specific case herein, whereby the cross-section through which the liquid flows is a right-angled channel, one arm of which being longer than the other arm by a factor of 16.5, the flowing water is considered as a streaming fluid through a narrow crack. In this case, the Reynolds number is determined by the formula:

$$Re = [V L] / \eta, \quad (2)$$

where L is the channel characteristic dimension. In this case, the gap width = 6.00 mm. With reference to Fig. 13, for the flow of water through the electrode cassette, there is:

$$\rho = 1000 \text{ kg/m}^3, \text{ and } \eta = 0.01 \times 10^{-68}.$$

The W2W electrochemical reactor and system operate at impure water throughput of $Q =$ from 1.0 to 3.0 m^3/hour . Knowing the cross-sectional area S to be

0. $100 \times 0.006 \text{ m}^2$, and the number of electrode cassettes in the electrochemical reactor, the flow velocity, V , is determined according to the formula:

$$V = Q / S \cdot 3600 \cdot 0.006 = 0.116 Q \text{ m}^3/\text{sec} \quad (3)$$

Formulas (2) and (3) are used for taking into account the value of the

Reynolds number and of the flow velocity, V , at various values of the water throughput, Q , as follows:

$Q\text{m}^3/\text{s}$	0.5	1.0	1.5	2.0	2.5	3.0
$V\text{m/s}$	0.116	0.174	0.232	0.290	0.348	
Re	773	1160	1546	1933	2320	

If the Reynolds number does not exceed a certain critical value, then the flow behavior of the water is laminar. If the Reynolds number exceeds a critical value, then the flow behavior becomes turbulent. For smooth tubes and nonviscous fluids, the critical Reynolds number is around 2300. In other cases reported in the literature, the transition conditions occur at a critical Reynolds number of around 1700. It is noted that the initial temperature gradient at the level of the electrode cassettes, and 30 the evolution of gas in the process of flow between the electrodes, in the electrochemical reactor, make the critical Reynolds number rather lower, affecting the onset of turbulent flow.

In the case where considerable control of water throughput is exercised, it is emphasized that upon exit of purified water at a rate of at least 2.0 nf/hour, the flow through the inter-electrode gap could become turbulent. For normal electrochemical reactions under conditions of improved ion diffusion assisted by the electric field, ordinarily, the laminar flow regime is the rule rather than the exception.

Automatic Feedforward and Feedback Control of the W2W System

For describing automatic feedforward and feedback control of the W2W 10 system, reference is made to Figs. 14 and 15. Automatic control of the W2W system permits processing of impure water without intervention at the given production output. Impure water undergoing processing goes through the following stages: preliminary filtration 40, electrochemical treatment 31, sedimentation 41 and 42, point filtration 43 and ion exchange 44. The flow of water through all treatment 15 stages is subject to constant automatic control to enable full and proper operation of all parts in the hydrodynamic cycle with the one and only purpose of producing a proper output and avoiding “out-of-

control” or “runaway” situations.

Automatic control of the W2W system is carried out by a programmable electronic controller. It is necessary to use a lock-up configuration of the 20 hydrodynamic system. The basic system version operates as follows: the water to be treated passes first into a system buffer tank 30, in which the water level is determined. The first buffer tank 30 is required in order to regulate the water flow from the demand tank and adjust it to the required flow rate through the system. The water level is determined by means of a level sensor 24, which establishes the 25 existence of any of three significant water levels in the tank.

The lowest level

indicates the lowermost allowed water level in the tank and the minimum admissible quantity.

The power supply controller 1 (Fig. 15) receives data on the water level as a signal indicating whether first buffer tank 30 is empty and must be replenished. The 30 second level occurs between the low level and the top level. In this region, the controller 1 issues a command to undertake one of two possible processes, either replenish first buffer tank 30 by opening a valve 26, or empty first buffer tank 30 through the runout valve. The third level indicates top water level in the tank, or above it. The controller 1 interprets this case by issuing a signal “tank full” requiring closure of the filling valve.

Tank valve 26 from the first buffer tank 3.0 is the first valve in the basic version of the system. There is also a second release valve 28 for a second buffer tank 5 27. Water enters second buffer tank 27 through electrochemical reactor 31 and sedimentation containers 41 and 42. The electrochemical reactor 31 receives power from a power source and control unit 29, but only when water enters the electrochemical reactor 31. The minimum sufficient water flow through the electrochemical reactor 31 which would operate power source and control unit 2 9 is 10 triggered by a flow sensor 32. Flow sensor 32 is installed at the electrochemical reactor input where it senses incoming water. Other functions of flow sensor 32 are additional control of the hydrodynamic chain, from the first

buffer tank 30 down to the point where the flow sensor is installed.

Data control is performed as follows. If a command is issued to open the first valve 26, a stream of water flows down through first valve 26, and if this stream turns out to be improper, that is, there is a problem at the top part of the hydrodynamic chain, and the system is threatened by a potentially disorderly or unstable situation, then the second buffer tank 27 serves to adjust the water flow after sedimentation 41 and 42, and regulates this flow after passing through various filters 43 and ion exchange columns 44.

Random overfilling of the second buffer tank 27 is prevented by several measures. One of these is the preliminary indication of water flow entering the second buffer tank 27 and exiting that tank. This indication causes special measures to be taken for regulating the flow of water. Control of the water flow is carried out according to the readings of a flow meter 45. A preliminary indication of the water flow takes place when the water input into the second buffer tank 27 is 5 - 10 % less than the water flow out of the second buffer tank 27. The second buffer tank 27 is provided with a level sensor 25, which serves for control of a second valve 28 and operates the second valve in case of overfilling of the second buffer tank 27. Such overfilling may occur due to erroneous initial indication of water flow in the flow regulator or due to a failure causing water flow from the hydrodynamic part to the second buffer tank 27. Therefore, lack of water level control at the second buffer tank 27 relative to the control of water level at the first buffer tank 30 could give rise to overfilling, and in turn to shutoff of the first valve 26. Cancellation of the blocking of the first valve 26 leads, if the water level in the second buffer tank 27 reaches the mean level, to a control indication analogous to high level being reached in the first buffer tank 30. Thus, when the water level reaches intermediate value in the second buffer tank 27, the second valve 28 opens. When the water level in the second buffer tank 27 reaches low level, the second valve 28 closes.

Water pressure in the ion-exchange columns 44 is limited to 1 bar. If the pressure exceeds this value, this may damage system components. A manometer 45 is installed to record the pressure, at the hydrodynamic chain next

to the ion-exchange columns 44.

10 Power Input to the Electrochemical Reactor

The flowing impure water is processed in the electrochemical reactor (20 in Figs. 2, 3, 4, 8, and 9; 31 in Fig. 14). Depending on the initial ion concentration, the flowing impure water may have widely varying conductivity. Effective breakdown of the impure water requires the best use of electrical input power, to enable the 15 automatically controllable power source (29 in Figs. 14 and 15) of the electrochemical reactor to work with highest efficiency. Since the conductivity of the flowing impure water varies within a wide range, this is not a simple task to accomplish, since the maximum power delivered by the power source to the load, $W_{\max} = U_{\max} \times I_{\max}$, is strictly limited, where U_{\max} is the maximum voltage of the power source, and I_{\max} is the maximum current this source can supply.

The maximum voltage and current may only be obtained at the same time for strictly defined specific conductivity of the impure water, $S_{b_{\text{est}}} = KR_{l_{\max}}/U_{\max}$, where Kr is a coefficient defined by the relation $Kr = S_w R_r$, where S_w is the specific conductivity of the impure water, R_r is the electric resistance of the electrochemical reactor at S_w , and Kr is a quantity dependent on the electrochemical reactor output at the given temperature and throughput of the water flowing through the electrochemical reactor, that is, determined by the particular structural configuration of the electrochemical reactor. This means that a power reserve, herein, referred to as AW , must be provided. Accordingly, if S_w does not equal $S_{b_{\text{est}}}$, that is, the power supplied by the power source is less than the nominal power W_n , whereby $W_n < W_{\max}$, then the power reserve $AW = W_{\max} - W_n$.

Let us determine AW relative to W_{\max} , in case S_w changes by a factor of 2, that is, $K_g = S_{\max}/S_{\min} = 2$. The value $K_s = 2$ is common in practice and is not exceeded as long as the same impure water is processed. This means that when, for example, $I_{\text{Inst}} = U_{\max}$, the current may vary from I to I_{\max} , where $I_{\max} = K_s I_n$, and correspondingly $AW = W_{\max} - W_n = U_{\max} I_{\max} - U_{\max} I_n = U_{\max} I_{\max} (K_s - 1)$.

($1 - 1/K_s$). The relative pOWCf reserve will then be $K_w = AW/W_{max}$:

$$K_w = AW/W_{max} = U_{max} I_{max} (1 - 1/K_s) / U_{max} A_{max} = 1 - 1/K_s = 1 - 1/2 = 50 \%$$

This shows that for a conductivity variation whereby $K_g = S_{max}/S_{min} = 2$, the power reserve required is 50 %, which turns out in fact to be slightly in excess of the power required. The operating power source is therefore fitted with a smooth current limiter (6 in Fig. 15), in order to maintain a nominal power within a range from 1.5kW to 2kW upon variation of conductivity by a factor of 2 for each

electrochemical reactor. The maximum power supplied by each source is $W_{max} = 2kW$. Such a source of power, not lower than 1.5 kW, supplies a current and voltage varying between the limits $I_1 = 32A$, $U_1 = 48V$, and $I_2 = 49 A$, $U_2 = 32V$. Here, $K_s = R_1/R_2 = U_1/I_1 / U_2/I_2 = U_1 I_2 / U_2 I_1 = 48V \times 48A / 32V \times 32A = 2.25$.

15 Current limitation is applied when the current reaches 42A and the voltage reaches 48V, a condition of maximum power $W_{max} = 2kW$, but the power excess does not exceed $K_w < 25 \%$, whereby K_s is not less than 2, since prolonged reduction of the load resistance makes the voltage fall automatically, and the current then increases. Another requirement which a universal power source, applicable to the 20 electrochemical reactor of the W2W system, must fulfill is the following. The initial conductivity of impure water, as pointed out above, may vary by a factor of 2, but only in case the impure water to be processed has a certain well defined ionic composition. For other ionic concentrations, an additional power source is connected in series, when the initial conductivity of the impure water is much lower, or the 25 power sources have other current and voltage ranges. In practice, it is entirely satisfactory to make use of power sources having one of the following current and voltage ranges:

(a) $W_{max} = 42A \times 48V$, and (b) $W_{max} = 24A \times 84V$.

Analysis shows that it is more expedient to use an energy supply mechanism 30 featuring synchronized combination of two power sources, and not let one power

source supply energy to the electrochemical reactor. Connecting power sources either in series or in parallel is a practical way for tackling the

conductivity range of impure water sources processed in the same electrochemical reactor. Series connection of power sources permits the source voltage to be doubled, whereas parallel connection permits the source current to be doubled. By using two power sources each having a maximum current and voltage I_m and U_m , respectively, it is possible to obtain from this combination in series connection a power of $W_s = (2U_m) \times I_m$, or, for a parallel connection $W_p = U_m \times (2I_m)$. In order to obtain such a current and voltage range from a single power source, that source must be capable of supplying power, $W = (2U_m) \times (2I_m)$, such that $W_u/W_p = W_u W_s = 2$, that is, a two-fold power reserve, which in practice means twice the cost and twice the facility size.

Synchronized Operation of Electrochemical Reactor Power Sources in Series or in 10 Parallel with the Electrode Cells of the Electrochemical Reactor
The control algorithm of power sources is based on synchronized supply of power to the electrodes of the electrochemical reactor in the range W_n to W_{max} , where W_n is the nominal power and W_{max} is the maximum power. The electrodes in the electrode cells of the electrochemical reactor are connected in such manner that the 15 voltage across the electrodes is synchronously obtained either by a series connection, or by a parallel connection, of the power sources.

Series Connection

Reference is made to Figs. 16 and 17. In a series connection of the power supplies (PS1 and PS2), the regulated voltage across the electrodes of the electrode 20 cells of the electrochemical reactor acts on the side-by-side electrodes of the same polarity, whereby all positive electrodes of the electrode cells in the electrochemical reactor are interconnected and all negative electrodes are also interconnected, for synchronous operation of the electrode cells in the electrochemical reactor.

Parallel Connection

25 Reference is made to Figs. 18 and 19. In a parallel connection of the power

sources (PS1 and PS2), the source currents are added together. However, since the PLC (Programmable Logic Controller) allows the possibility of pseudo-parallel connection, permitting full release of power to any of the electrodes of the electrode cells in the electrochemical reactor, this simplifies the control of each electrode cell to 30 the required current.

Pseudo-parallel Connection

Reference is made to Fig. 20. Each power source (PS1 and PS2) is applied to an assigned electrode cell in the electrochemical reactor, whereby the regulated voltage across the electrode cells depends on the given voltage controlled by the PLC, so that the power provided to each electrode cell is never less than W_n . At that power level, the nearness of the voltages across the electrode cells to one another is determined by the accuracy of PLC control over the power sources.

Power sources are synchronously switched on and off, for a series connection, a parallel connection, as well as for a pseudo-parallel connection. When the power sources are switched on, their voltages synchronously rise to the required value within less than 0.5 second.

Power Source Control Board Interface 10 Reference is made to Fig. 21. In

Fig. 21, the power source control board

interface includes the following main components: manual controller of output voltage 1, control logic 2, pulse-width modulator 3, current sensor 4, voltage amplifier

5, voltage-to-frequency converter 6, current protection comparator 7, opto-isolator 8.

The power source control assembly, or control board interface (also, partly 15 described above and illustrated in Fig. 15), executes the following functions:

- Remote switching of the system power source on and off.
- Control and synchronization of output voltage in accordance with the data.
- Current limiting (6 in Fig. 15).
- Thermal protection.
- Protection against brief mains voltage variations.

- Issuing a 'ready' signal at the PLC (Programmable Logic Controller) input.
 - Provision of pulses of a frequency proportional to the output voltage at the PLC input.
 - Provision of pulses of a frequency proportional to the output current at the 25 PLC input.
 - Use of pulse-width modulation (PWM) (1 in Fig. 15) for voltage control.
 - Regulation of power source output voltage.
 - Galvanic decoupling of all internal control commands from the internal data transfer bus.
1. The power source may be switched on and off by one of the following two modes:
 - a. providing a voltage of 24V to the opto-isolator.
 - b. closure of the normally-open contactor relay.
 2. The output voltage may be regulated by one of the following two modes:
 - a. with a potentiometer.
 - b. by applying positive 24V pulses of varying width to the opto-isolator.
 3. Current limitation is carried out by applying 500 nsec long pulses at the current-limiting input of the PWM controller. This forces reduction of the impulses at
 - 5 the PWM output, lowering the voltage of the power source and thus bringing about a limitation of the power source output current.
 4. The thermal protection is activated in case the heat-sink temperature reaches 60 °C. This forces a shutdown of the power source output voltage.
 5. Protection against brief fluctuations in mains voltage is activated when the
 - 10 load current limit is attained and forces shutdown of the output voltage.
 6. Provision of a 'ready' signal at the PLC input indicates that the power source is running normally.
 7. Data transfer to the PLC input concerning the power source output current is carried out by voltage to frequency conversion, whereby the frequency

is

15 proportional to the load current. This frequency varies over the range 0 to 10kHz, the last value corresponding to the maximum load current.

8. Data transfer data to the PLC input concerning the output voltage of the power source, is also carried out by voltage to frequency conversion, whereby the frequency is proportional to the power source output voltage. That frequency varies

20 over the range 0 to 10kHz, whereby the frequency of 10kHz corresponds to the maximum output voltage of the power source.

9. The PLC can regulate the output voltage of the power source by emitting pulses at a frequency of 1kHz of width varying over the range 0 to 100%, whereby 100% corresponds to the maximum output voltage of the power source.

25 10. Regulation of the output voltage of the power source is carried out by feeding back the power source output voltage to the input of the PWM controller.

11. All connections to the PLC are provided with galvanic decoupling by means of opto-isolators, which isolate voltages of up to 1.5kV (RMS) at the power source output from the data transfer control bus of the PLC.

30 Method of Electrochemical Reactor Operation and Control - Synchronization of Electrochemical and Hydrodynamic Mechanisms

Electrochemical reactor operation is controlled by the PLC (Programmable Logic Controller). The PLC receives data on the electrochemical reactor throughput,

current, and voltage. Electrochemical reactor throughput is recorded by a flowmeter. If the throughput is too high, the PLC issues a command to the synchronized power sources. Power is provided to the electrochemical reactor only in case the throughput is not lower than a given threshold. This makes it possible to avoid electrochemical reactor overheating if the flow through them is insufficient. The electrochemical reactor current in case of series connection of the power sources is determined by the power source output current: $I_{ps} = 2IR$,

where I_{ps} is the power source output current, and I_R is the current of each of the two electrode cells.

The voltage across the electrode cells of the electrochemical reactor is $V_R = 10 V_{psi} + V_{ps2}$, where V_{psi} and V_{ps2} are the voltages of the first and second power sources, PS1 and PS2, respectively. The PLC thus obtains data on the current and voltage of the power sources and the synchronized power supplied to the electrode cells of the electrochemical reactor.

In the case of parallel connection, $I_{psi} = I_{ri}$, $I_{ps2} = I_{r2}$, where I_{psi} and I_{ps2} are the currents of the power sources, and I_{ri} and I_{r2} are the electrode cell currents. $V_{psi} =$

V_{ri} , $V_{ps2} = V_{r2}$, where V_{psi} and V_{ps2} are the voltages of the power sources, and V_{ri} and V_{r2} are the voltages across the electrode cells. The PLC equalizes the voltages across the electrode cells and provides them both with the same given voltage V , so that $V = V_{psi} = V_{ps2} = V_{ri} = V_{r2}$. In this way the voltages across the electrode cells are synchronized in the case of parallel connection.

Part 3~Exemplary “Actual” Practice and Applications, and Analysis of Results Obtained Therefrom

The following is a detailed description of several exemplary “actual” practices and applications, and analysis of results obtained therefrom, of the Mey Rechavam 25 (W2W) water treatment / purification / regeneration system.

Estimate of Operating Efficiency of The W2W Water

Treatment/Purification/Regeneration System for an Input of Water Containing a Measured Amount of Various Metals

1. Composition of the loaded water 30 In order to test out the capability of the W2W system, a special quantity of water was prepared in two, 200 liter portions, identical and to be tested in parallel. Each portion consisted of tap water only, plus an aqueous solution of the following metals:

—200 ml of solution containing Cu (140.000 ppm).

—200 ml of solution containing Ni (30.000 ppm).

- 200 ml of solution containing Mn (30.000 ppm).
- 200 ml of solution containing Zn (30.000 ppm).
- 200 ml of solution containing Cr (1.000 ppm).

5 In each of these portions the metal concentrations were as follows:

- Cu: 90 to 105 mg/l (ppm).
- Ni: 25 mg/l (ppm).
- Mn: 20 to 25 mg/l (ppm).
- Zn: 25 to 35 mg/l (ppm).

10 —Cr: 15 to 20 mg/l (ppm).

2. Technical characteristics of the W2W system (serial no. 3-0015)

The general scheme of the W2W system used is shown in Fig. 22 As shown in Fig. 22, the W2W system includes the following main components: input tank X input water flow meter 2, the electrochemical reactor 3 including two electrode cells 15 connected in parallel, sedimentation tanks 4, and reactor output intermediate storage/transfer tank 5.

2.1 The electrochemical reactor 3 contains 4 electrode cassettes (2 in each electrode cell). The anodes are made of aluminum, the cathodes of stainless steel. The cassettes are without a membrane.

20 2.2 The test portions included 3 portions of 80 liters each. The total quantity was 240 liter. The water in each portion was let in and withdrawn separately, that is, in parallel. At the input each portion was passed through woven filters of 50 micron mesh.

2.3 Reserved portion: 200 liters meters of water was preserved after sedimentation 25 (catholite), as well as directly from the electrode cells (anolyte). The anolyte

water was also filtered through a 50 micron mesh.

2.4 Power source. Two synchronized power sources were installed in the W2W system, each supplying a 50A current at 60V.

3. Point of water sampling

30 Sampling of the flowing water was performed according to the W2W system

water sampling plan shown in Fig. 23. Sampling points, also referred to as tapping points, were selected so as to enable obtaining an estimate of efficiency of the electrochemical reaction, and, of the sedimentation and filtration processes.

4. Measuring Instrumentation

- 4.1 Metal content in the water was determined with a PF-11 photometer and the set of kits for metal assay manufactured by the firm of Visocolor:

2[^].

—Cu test kit for copper determination, 0.1 - 3.0 mg/1 Cu .

—Ni test kit for nickel determination, 0.2 -10 mg/1 Ni²⁺.

- 5 —Mn test kit for the colorimetric determination of manganese in the range of 0. 1 - 4.0 mg/1 Mn.

—Zn test kit for zinc determination 0.25 to 3 mg/1 Zn .

—Cr test kit for chrome determination 0.1 to 2 mg/1 CrO₄²⁺.

- 4.2 The conductivity was measured using a conductivity meter model CD-4301.

10 4.3 pH was measured using an AD 10 pH meter.

- 4.4 The energy dissipated in the cassettes was measured using an ammeter (Fc-8 Op) and a voltmeter (Dixsen DE-80).

- 4.5 The water throughput in the electrode cell of the electrochemical reactor was measured using a George Fischer SR20 flowmeter.

15 5. Test results

The test results are presented in Tables 1 and 2.

6. Analysis of the test results

Based on the test results reported in Tables 1 and 2, electrochemical reactor operation is analyzed (6.1), and the types of sediments on the 50 micron mesh filters,

20 as well as on such filters from the anolyte in the reserve quantity, are listed

6.1 Electrochemical Reactor Operation

Effectiveness of water purification from metals is shown in Table 4. To estimate the effectiveness, mean values were calculated from the data obtained in the

two tests (Tables 1 and 2), according to the analysis of water entering into and exiting 25 out of the electrode cells (separately for the catholite and anolyte).

Table 4

Metal	Cu	Ni	Mn	Zn	Cr
Purification effectiveness on input line - anolyte, %	80	96	80	61	42
Purification effectiveness on input line - catholite, %	87	95	96	73	35

The effective operation of the electrode cells of the electrochemical reactor is due to the low flow velocity, 0.06 m/s, of the water flowing through the electrode cassettes, and to the markedly long transit time, 5 sec, of the water flowing between the electrodes. At such flow velocity, the Reynolds number, Re , previously defined 5 by equations (1) and (2) and described above, is less than 500, and the flowing water is consequently laminar. Laminarity is conducive to thorough breakdown of the entering water.

Chemical reactions taking place in aqueous solutions next to electrodes may be considered as redox reactions. Electrolysis thus consists of a reduction reaction at the cathode and an oxidation at the anode. A metallic anode may be (a) non-dissolving and only acting as an electron transfer site during electrolysis, or (b) dissolving (active) whereby it is oxidized upon electrolysis. The redox activity of the electric current in many cases reinforces chemical oxidation and reduction reactions. Examination of the tables of standard electrode metals shows the following:

- Metal cations, for example, Cu^{+2} , Hg^{+2} , Ag^{+} , Pt^{+2} , and Pt^{+4} , having a standard electrode potential greater than that of hydrogen, during electrolysis are completely dissolved either at and/or by the anode, and are deposited in metal form onto the cathode.
- Metal cations, for example, Li^{+} , Na^{+} , K^{+} , and Ni^{+2} , down to Al^{+3} , having a standard electrode potential less than that of hydrogen, during electrolysis, remain attached to the anode without dispersing among the water molecules.
- Metal cations, for example, Mn , Zn , Cr , and Fe , having a standard electrode potential less than that of hydrogen, and greater than that of

aluminum, during electrolysis, deposit onto the cathode, and become dispersed among the water molecules.

For a metal cation total concentration of larger than 200 mg/l (200 ppm), then the ionic concentration is relatively high. As a result of this, there is a type of interion secondary affect, whereby each ion influences to a varying degree or extent, the 30 measurement, via the spectrophotometer, of the total ionic concentration of the flowing water. With regard to strong ionic solutions, the above analysis results may be somewhat affected by ion attachment to other metals. According to the test results obtained herein, there is a general tendency towards consistent behavior, but the quantitative relationships may vary.

6.1 The effectiveness of sedimentation (as shown by the filters) is supported by the results of the water analysis after passing through the electrochemical reactor (catholite) and at the entry. The results are presented in Table 5A.

Table 5A

Metal		Cu	Ni	Mn	Zn	Cr
Effective separation in the catholite line - sedimentation %		64	30	50	86	72

It follows from the experimental results that the hydrodynamic efficiency (sedimentation rate of metal hydroxy compounds) differs. Hydroxy compounds of

zinc, chromium and copper coagulate and precipitate sufficiently well, but those of nickel and manganese do not. Presence of nickel and manganese hydroxy compounds 10 in polluted water may therefore reduce the effectiveness of operation of the electrochemical reactor, their sedimentation may take longer, a larger volume needs to be processed, or, the throughput will be slower.

6. 3. The effectiveness of capture of metal ions and their hydroxy compounds on a 50- micron mesh filter at the anolyte entry is shown in Table 5B.

Table 5B

Metal	Cu	Ni	Mn	Zn	Cr
Effectiveness along the anolyte line - reserve %	67	29	25	98	0

The results shown in Table 5B show good retention capability relative to the i

coagulated sediments of zinc and copper hydroxy compounds, moderate ability in retaining nickel and manganese hydroxy compounds, and complete non-suitability of 20 that filter for the retention of chromium hydroxy coagulation species.

Overall, the experimental test of water treatment/purification capability using water loaded with various metal complexes showed effective operation of the W2W system, with regard to sedimentation capacity, filtering, and electrochemical reactor operation. Total water treatment/purification effectiveness is represented in Table 6, 25 along with reference made to Fig. 20.

Table 6

Metal				Cu	Ni	Mn	Zn	Cr
anolyte, % removed via				95	98	85	99	50
catholyte, % removed via				96	97	98	97	82.5

As shown by the above results, the W2W system is very effective for treating / purifying water loaded with metal complexes. In the case of chromium, the effectiveness is reduced by 50 % because the mesh filter used does not effectively retain chromium hydroxy coagulation products. For all other metals, the effectiveness is at least 85 % (somewhat low for manganese), and about 95 % for all other metals (copper, nickel, and zinc).

Test of the Effectiveness of Operation of the W2W Electrochemical Reactor and System

The effectiveness of operation of the electrochemical reactor was estimated on a W2W series-production system under normal conditions at the Mei Rechavam works. The loaded water for the test was local tap water, to which CuSO₄ was added in a quantity to make the concentration of copper at the input to the electrochemical reactor about 50 to 100 mg/l (ppm). The main tasks of this test were the following:

1. Estimation of the influence of electrochemical reactor throughput on the effectiveness of reducing metal ion concentration.
2. Estimation of the influence of electrode material on the effectiveness of reducing metal ion concentration.
3. Estimation of the influence of membrane inserts in the cassettes on the effectiveness of lowering metal ion concentration.

In addition, it was necessary to estimate the expediency of using two synchronized power sources, connected either in parallel or in series. Water samples were taken from the input as well as from the output of the electrochemical reactor (from the anolyte as well as from the catholyte line). The measuring instrumentation used was already described hereinabove. The tests were conducted with two types of power sources: 50A/60V, and 30A/100V. The test results are presented in Tables 1-

Analysis of the test results shows the following:

1. In all cases, less copper collected on the anode than on the cathode (also after filtration). This indicates that copper in the output water was present as CuSO_4 . Water flowing over the electrodes led to dissociation of CuSO_4 into the ions Cu^{2+} and SO_4^{2-} . Copper ions drifted (in the absence of a membrane) to the cathode, where they either formed hydroxy compounds, such as $\text{Cu}(\text{OH})_2$, which is insoluble and precipitates, settling in the sedimentation tanks and on the filters, or settled in as pure copper on the cathode surface. Due to the drift of Cu^{2+} ions from the anode towards the cathode, the anolyte contained fewer copper ions and hydroxy compounds.
2. When the current was stepped up, increasing across the electrodes from 55A up to 96A, the effectiveness of concentration reduction also increased. For example, for an anode and cathode used for testing each made of 10 material, for example, solid aluminum, the percentage was 44.6 % in the anolyte, and 25 % in the catholyte.
3. The effectiveness of concentration reduction also depends on the electrode material. According to the effectiveness obtained, desirable electrodes are graded in the following order: Al - Al (aluminum), Ti - Ti (titanium), and SS - SS (stainless steel). It is apparent that the anode material has the largest effect.

It is interesting to make the comparison between and analyze the experimental results. Medium effectiveness for reducing the concentration of copper, both in the anolyte and in the catholyte, was obtained without having a membrane in each 20 electrode cassette, amounting to 56 % and 20 %, respectively. With a membrane, the results were 29 % and 9 %, respectively. For operating the electrochemical reactor having the electrode cassette with a membrane, the energy demand or consumption is estimated from the input power to have been at least twice as large compared to using the electrode cassette without a membrane. Thus, the results conclusively show 25 higher effectiveness for reducing Cu ion concentration and lower energy demand or consumption for operating the configuration of the electrochemical reactor

having the electrode cassette without a membrane, compared to operating the alternative configuration of the electrochemical reactor having the electrode cassette with a membrane.

In all cases considered above, two synchronized power sources were used, connected in parallel or in series. The use of two synchronized power sources can lead to results equivalent to those obtainable with a single power source but, with two power sources, the power required is halved. Thus, for example, using a current of 96A supplied to four electrode cassettes, which is more effective for lowering the concentration of copper, requires a voltage of 26V, for the case of two synchronized power sources connected in parallel.

The power input was 2.496 kW. Effectiveness of Cu concentration reduction in the anolyte was 94 %, and 35 % in the catolyte. Each of the two power supply 5 sources (PS1 and PS2, Figs. 16-19) was supplied at 48A and at 26V. If a single water source would be used for obtaining the same current, that is, for the same water conductivity, then to get a current of 96A requires increasing the voltage from 26V to 52V, thus multiplying the source output power by a factor of 2, in order to reach the a power of 4.99 kw.

Based on operation of the W2W system, along with the aforesaid results and analysis, the following conclusion is arrived at: to obtain the most effective current through the electrode cassettes, in our case 96A, it is most expedient to use two synchronized power sources. This reduces required power output by a factor of 2 for the same effectiveness of operation of the electrode cells in the electrochemical 15 reactor.

Use of the W2W Water Treatment/Purification/Regeneration System for Reducing Water Hardness

The problem of reducing the hardness of water supplied to steam boilers and the like is of great importance in commercial applications. A test was conducted at 20 Mey Rechavam Ltd. works to examine the possibility and effectiveness of using the W2W system, without additional resinous ion-exchange columns, for the reduction of

water hardness. The experiments were conducted using the W2W system, schematically illustrated in Fig. 24, having various sedimentation capacities, for example, 360 and 420 liters, as supplied by a preliminary tank². As stated, in this 25 test case, the columns were not charged with ion-exchange resin. The raw water used was ordinary tap water from the mains of the southern town of Sderot, Israel. The pair of oppositely charged electrodes were constructed of two different types of material: stainless steel (SS), and aluminum (Al), respectively. The water was tested using the following means:

1. Total hardness - test kit for determination of total hardness, model H70F, made by Visocolor.
2. Water conductivity - using a CD-4301 conductivity meter.
3. pH - using an AD-100 pH meter.
4. Water throughput in the W2W system - using a Georg Fischer SK2 flowmeter.

The load on the electrode cassettes was measured using an FS-80 ammeter and a Dixsen DE-80 voltmeter, mounted on electronic racks. Electrical energy was supplied by two synchronized power sources connected in parallel, providing 50A and 60V.

Sampling of the flowing water, at various tapping points, was performed according to the W2W system water sampling plan shown in Fig. 25. Test results obtained using the W2W system are presented in Tables 1 and 2. Analysis of the 10 results listed in Tables 1 and 2, shows the following:

1. For all test regimes, the total hardness value of the water at the system output was 13 to 14 °d (degrees of hardness, German scale).
2. The test results lead to the conclusion that the final result is not materially affected by the water throughput (1000, 2000, or 3000, liters / min), nor by the type of electrode material, Al or SS, nor by the capacity, 360 and 420 liters, of the sedimentation tank.

Physical and chemical examination of the obtained results show highly effective operation of the electrochemical reactor and sedimentation tank. In effect, a test of the input water by boiling and filtering showed that total water hardness was 20 12.5 to 13 °d (degrees of hardness, German scale). It is known from theory that total hardness is made up of a constant hardness plus a time-dependent hardness, and that in boiled and filtered water, only the constant hardness remains. Consequently, processing of water using a W2W system should lower the time-dependent hardness.

The hardness of the output water had a very acceptable value of 0.5 to 1.5°d. It is known that time-dependent hardness is a component of the total hardness, and constitutes a major risk factor in technology. This is due to the fact that time-dependent hardness is due to the presence of potassium and magnesium carbonates in water (CaCO_3 and MgCO_3). Upon heating of water these carbonates settle on internal surfaces of heating vessels, causing rapid deterioration of conditions for heat exchange, and consequently of the working order of heat-exchange facilities and equipment.

On the strength of the obtained results it may be stated that the calcium and magnesium carbonates, CaCO_3 and MgCO_3 , are effectively dissociated, in the electrode cells of the electrochemical reactor, into the corresponding ions Ca^{2+} , Mg^{2+} and CO_3^{2-} . In view of the presence in the water flowing between the electrodes, of the basic ion $(\text{OH})^-$ and of the acidic ion H^+ , these ions are expected to associate with the ions Ca^{2+} and Mg^{2+} , to produce the corresponding insoluble calcium and magnesium hydroxide salts, $\text{Ca}(\text{OH})_2$ and $\text{Mg}(\text{OH})_2$, respectively. These hydroxide salts were indeed deposited in the sedimentation tank and in the collection tank of the W2W system. In this way, use of the W2W system, without ion-exchange resin, appears to provide a highly effective means for reducing time-dependent hardness of water supplies.

Part 4. Detailed Description of How the Power Control of the Present Invention 10 Synchronizes the Power Supply to a W2W Electrochemical Reactor

The overall, general fundamental “patentable” concept and principle of the present invention is that the electrochemical reactor (electrode cells and electrodes therein, and housing thereof), along with its energy supply mechanism (interconnected power supply units and programmable logic controller), are 15 implemented for treating flowing water according to stable and integrated synchronized operation of electrochemical, electrocoagulation, and hydrodynamic, mechanisms.

A primary overall objective of the stable and integrated synchronized operation is to maximize use, and therefore, efficiency, of the energy generated by the 20 energy supply mechanism and supplied to the electrochemical reactor, in particular, the electrode cells and electrodes therein, for treating the flowing water.

Synchronized Operation of the Electrochemical Reactor (ECR) and the Energy Source Mechanism (ESM)

The electrochemical reactor (ECR), functioning as the physical location of 25 treating the flowing water, includes at least two, preferably, several, identically structured and operable electrode cells, wherein each electrode cell includes two electrodes - a cathode and an anode. The energy source mechanism (ESM), functioning as the source of energy for operating the electrochemical reactor (ECR) of the water treatment system, includes at least two, preferably, several, identically 30 operable power supply units (PSUs), and a programmable logic controller (PLC). The power supply units (PSUs) are appropriately interconnected to each other, to the programmable logic controller (PLC), and to the electrochemical reactor (ECR), according to various alternative configurations such that there is complete synchronization of the output parameters (voltage, current) generated by the power supply units (PSUs) and supplied to the electrochemical reactor (ECR).

During implementation of the water treatment system, the electrochemical, electrocoagulation, and hydrodynamic, mechanisms taking place inside the 5 electrochemical reactor (ECR), and the energy source mechanism (ESM) generating energy which is supplied to the electrochemical reactor (ECR), operate in a synchronized manner. Synchronized operation takes place in the time domain, from one water treating cycle to the next water treating cycle, during a period of operation lasting for a given amount of time or number of water treating cycles, where a water 10 treating cycle corresponds to a single cycle of treating or processing a single electrochemical reactor volume of incoming flowing water by the electrochemical reactor (ECR).

During synchronized operation of the energy supply mechanism (ESM), a single power supply unit (PSU) is designated the “master” power supply unit, herein, referred to as (m-PSU), operates on and is synchronized with the other “slave” power supply unit or units, herein, referred to as (s-PSU or s-PSUs, respectively). This master-slave type of synchronized operation of the power supply units (PSUs) is automatically controlled by the programmable logic controller (PLC) sending feedback signals to the master power supply unit (m-PSU). The feedback signals are 20 based on data and information continuously (typically, on the order of every 0.1 second) being sent to the programmable logic controller (PLC) by a plurality of strategically located sensors sensing various electrochemical, hydrodynamic, and electrical, parameters of the water flowing through the electrochemical reactor (ECR), and of the energy (voltage, current) generated by the power supply units (PSUs) and 25 supplied to the electrochemical reactor (ECR).

During the process of treating the flowing water, particularly as part of an automatic production line or more encompassing manufacturing process, synchronized operation of the electrochemical reactor (ECR) and of the energy source mechanism (ESM) is according to either a “steady-state” mode of synchronization, or, 30 according to a “non-steady-state” or “transient” mode of synchronization. In the “steady-state” mode of synchronization, the operating range of values of the output parameters (voltage, current) of the interconnected power supply units (PSUs) remains

constant, typically, to within about (+ / -) 1 %, from one water treating cycle to another water treating cycle, during a steady-state period of operation lasting for a given amount of time or number of water treating cycles during which the master power supply unit (m-PSU) operates on and is synchronized with the other “slave” power supply unit or units in a constant or steady manner. In the “non-steady-state” or “transient” mode of synchronization, the operating range of values of the output 5 parameters (voltage, current) of the interconnected power supply units (PSUs) varies, typically, by about (+ / -) 7 -10 % of the steady-state range, during a transient period of operation lasting for a relatively short amount of time, typically, on the order of less than one second, during which the master power supply unit (m-PSU) operates on and is synchronized with the other “slave” power supply unit or units in a non-steady- 10 state or transient manner, until there is quick return to a steady-state mode of synchronization.

Ordinarily, for example, for at least about 90 % of total operating time, the electrochemical reactor (ECR) and the energy source mechanism (ESM) operate in the steady-state, rather than a non-steady-state or transient, mode of synchronization. 15 At various instantaneous times during the remaining part of the total operating time, either controllable or uncontrollable, situations or instances occur where there is a spontaneous or instantaneous transition from a steady-state to a non-steady-state or transient mode of synchronized operation. An example of this phenomenon is the situation when the water flowing into the electrochemical reactor (ECR) suddenly 20 stops flowing for a relatively short, but finite, period of time. Additional examples of this phenomenon are situations when one or more parameters (conductivity, linear velocity, volumetric flow rate, chemical concentrations, temperature, and gradients thereof) of the water flowing through and treated inside the electrochemical reactor (ECR) suddenly “spikes” in the form of either an increase or decrease. Accordingly, 25 the electrochemical reactor (ECR) and the energy source mechanism (ESM) are designed and operated with the objective of being rapidly adaptable to constant as well as variable operating conditions, whereby a spontaneous or instantaneous transition from a steady-state mode to a non-steady-state or transient mode, and return to a

steady-state mode, of synchronized operation, occurs within less than 1 second.

The steady-state mode of synchronized operation of the power supply units (PSUs) of the energy supply mechanism (ESM), as well as that of the electrochemical reactor (ECR), is based on a dynamic symmetry of the structure, function, and operation, of the electrochemical reactor (ECR). Following below are the main parameters defining the properties, characteristics, and behavior, of this dynamic symmetry:

Structural and functional equivalence, uniformity, and symmetry, of all components and elements of the electrochemical reactor (ECR), in particular, the 5 electrode cells and the electrodes therein, and the water flow channels inside and outside of the electrode cells. In particular, wherein a given configuration and structure of the electrochemical reactor (ECR), each electrode cell is identically structured and configured. More specifically, regarding the electrodes, such that the (i) geometrical shape or form and dimensions, (ii) material or materials of construction, and (iii) physicochemical properties, characteristics, and behavior, of the anode of a first anode-cathode electrode pair are as identical as practically possible to those of the anode of each other anode-cathode pair in the same electrode cell, for each and all the electrode cells in the same electrochemical reactor (ECR). The same applies to the cathode of each anode-cathode pair in the same electrochemical reactor (ECR). It is noted that above characteristics (i), (ii), and (iii), of a given cathode may, but need not, be identical to those of the anode of the anode-cathode pair. For typical implementation of the present invention, the above characteristics (i), (ii), and (iii), of a given cathode are different than those of the anode of the anode-cathode pair.

- Equivalent, uniform, and symmetrical, static and dynamic operation of all 20 components and elements of the electrochemical reactor (ECR), in particular, the electrode cells and the electrodes therein, and the water flow channels inside and outside of the electrode cells.

- Equivalent, uniform, and symmetrical, operation of electrochemical, electrocoagulation, and hydrodynamic, mechanisms taking place in the 25 electrochemical reactor (ECR). Specifically, as relating to electrical charges on

and along the electrode surfaces, and as relating to the parameters (conductivity, linear velocity, volumetric flow rate, chemical concentrations, temperature, and gradients thereof) of the flowing water and components therein, throughout the water flow channels inside and outside of the electrode cells, inside the electrochemical reactor 30 (ECR).

--Equivalent, uniform, and symmetrical, calibration of all components and elements of the electrochemical reactor (ECR), in particular, the electrode cells and the electrodes therein, and the water flow channels inside and outside of the electrode cells.

—A set of parameters of the dynamic symmetry relating to various possible non-steady-state or transient modes of operation of the electrochemical, electrocoagulation, and hydrodynamic, mechanisms, taking place inside the electrochemical reactor (ECR), that is, such states which do not have a pre-determined 5 or known energy requirement, and the extents of which are determined by a variable range of values of the parameters (conductivity, linear velocity, volumetric flow rate, chemical concentrations, temperature, and gradients thereof) of the water flowing through and treated inside the electrochemical reactor (ECR).

Hydrodynamic Synchronization 10

Figs. 2' and 3' are slight revisions of Figs. 2 and 3, respectively.

During operation of the electrochemical reactor (ECR), establishing and maintaining hydrodynamic synchronization are for achieving the following:

1. Uniformity and steady-state control of each of the various input and output flows of the water through the electrochemical reactor (ECR), during each water treating cycle.

2. Uniformity and steady-state control of the minimum level of energy consumption by the electrochemical reactor (ECR) of the various input and output flows of the water through the electrochemical reactor (ECR), during each water treating cycle.

3. Uniformity and steady-state control of the maximum level of energy

consumption by the electrochemical reactor (ECR) of the various input and output flows of the water through the electrochemical reactor (ECR), during each water treating cycle.

Immediately following are listed the main characteristics, features, conditions, and operating parameters, of hydrodynamic synchronization of the water flowing through and treated inside the electrochemical reactor (ECR).

—Several parallel continuously vertically ascending flows of water solution, identical with respect to all geometrical parameters and dimensions.

—Each flow is vertically directed and limited by functionally active surfaces of 30 the electrodes. Preferably, the electrodes are configured as rectangular, relatively flat, and parallel to each other, but may also be configured as cylindrical and coaxial with each other.

—Two electrodes in any electrode cell are entirely identical with respect to all geometrical parameters and dimensions, and their functionally active surfaces are like mirror images of each other.

—The electrodes are permeable to the flow of water solution at the entrance 5 into and exit from the inter-electrode space.

—The nature of interaction of the various water input and output flows with the functionally active surfaces of the electrodes, including local hydraulic resistance, is identical for all homologous points in all the flows.

—In each electrode cell, two flows of the water solution, separated by a mobile 10 inter-boundary layer (IB₁ and IB₂), pass in the space between the two electrodes, as shown in Fig. 26.

—Thickness of the mobile inter-boundary layer (IB₁ and IB₂) depends on the physicochemical properties, characteristics, and behavior, of the flowing water. In particular, viscosity; temperature; acidity or alkalinity level; presence of inorganic, organic, and/or biological, chemicals and/or chemical complexes (such as metal complexes); presence of chromium types of organo-metallic compounds (which are usually especially difficult to treat); hardness; and electrical conductivity. The thickness also depends on the

physicochemical properties, characteristics, behavior, and quality, and, geometry, of the functionally active surface of electrodes.

Other (hydrodynamic) conditions and parameters of the flowing water and the physical basis of these parameters follow hereinbelow.

1. Linear velocity, V , of the vertically ascending water flowing in between the inter-electrode space, in units of mm/sec:

$$V_i = V_2 = [F, \text{ volumetric flow rate (ml/sec) }] / [AS_j(\text{mm}^2)], \text{ where } AS;$$

is the area of the inter-electrode space cross-section, as shown in Fig. 26.

2. Duration, t , of the water treating cycle, in units of sec:

$$t = L_i / V_i = L^2 / V^2, \text{ where } L \text{ is the length of the functionally active surface of a given electrode, as shown in Fig. 26}$$

3. Difference in height, AH , between the supply or input channels and the 30 permeable zone of the electrodes in the area of exit (discharge):

$$H - AH = h, \text{ and } H + AH = H, \text{ as shown in Figs. 2' and 3'.$$

Degree of filling the volume of all the channels from the entrance to the exit of the inter-electrode space. Based on the use of internal pressure, denoted P . For a purely hydrodynamic synchronization, within a single electrochemical reactor (ECR), wherein the reactor includes two (2) electrode pairs, and four (4) parallel flows of water. Then, at any instant of time, and at any homologous point, the following conditions are observed (Fig. 26):

$$V_i = V_2 = V_3 = V_4 \text{ (for all four flows, at any point of the flow),}$$

$$t_j = t_2 = t_3 = t_4 \text{ (for all four flows, at any point of the flow, from the point of entry into the inter-electrode space),}$$

$$AH_i = AH_2 = AH_3 = AH_4 \text{ (for all four flows), and}$$

$$P_j = P_2 = P_3 = P_4 \text{ (for any identical point within the volume of any of the four flows).}$$

1. All the flows are hydrodynamically synchronized. Hydrodynamic synchronization is achieved by an appropriate design of the casing or housing of the electrochemical reactor (ECR). As shown in Figs. 2' and 3', the menorah-shaped labyrinth automatically divides the incoming

flow having flow rate F into two equal 15 identical flows having flow rates F_1 and F_2 , which are further divided by means of channels A, B, C, and D, (Fig. 2') into four identical flows having flow rates F_{1_i} , F_{2_i} , $F_{1_{i+1}}$, and $F_{2_{i+1}}$

2. Electro-hydrodynamic Synchronization

Immediately following are listed the main characteristics, features, conditions, and operating parameters, of electro-hydrodynamic synchronization of the water flowing through and treated inside the electrochemical reactor (ECR).

—Each electrode cell is identically structured and configured. More specifically, regarding the electrodes, such that the (i) geometrical shape or form and dimensions, (ii) material or materials of construction, and (iii) physicochemical properties, characteristics, and behavior, of the anode of a first anode-cathode electrode pair are as identical as practically possible to those of the anode of each other anode-cathode pair in the same electrode cell, for each and all the electrode cells in the same electrochemical reactor (ECR). The same applies to the cathode of each anode-cathode pair in the same electrochemical reactor (ECR). Above characteristics (i), (ii), and (iii), of a given cathode may, but need not, be identical to those of the anode of the anode-cathode pair. For typical implementation of the present invention, the above characteristics (i), (ii), and (iii), of a given cathode are different than those of the anode of the anode-cathode pair. Accordingly:

--All like electrodes are made of the same material(s).

--All like electrodes have the same cross-section area.

—Identical distance between pairs of opposite electrodes within the same electrochemical reactor (ECR) connected to the power supply units (PSUs) of the 5 energy supply mechanism (ESM).

-All electrodes have identical distance between entrance and exit.

—Length of the conductors forming the electrical connections or contacts between the power supply units (PSUs) and the electrodes is the same for all electrodes or pairs of electrodes.

—All like electrodes have identical cross-section area and specific resistance.

--Same nature of electrical connections or contacts for all like electrodes.

With all the above listed characteristics, features, conditions, and operating parameters, fulfilled, and provided that the instantaneous electrical conductivity of all the four flows of the water are identical, the electrochemical reactor (ECR) and the energy supply mechanism (ESM) operate according to an integrated electrohydrodynamic synchronization.

Example

Flowing water solution containing ~ 57.6 mg/l Cu and Cu as a part of CuSQ^* ; having pH = 6.5.

1 electrochemical reactor (ECR) with two cassettes, each cassette having two electrodes, with the anode made of aluminum (Al) having a thickness of 2 mm, and the cathode made of stainless steel having a thickness of 2 mm; distance between the electrodes is 6 mm, and the functionally active surface area = 3 dnT.

Necessary rate of consumption: 750 l/hr.

For one electrode: 187.5 l/hr.

For one electrode per 1 sec = 0.052 l/hr.

For one electrode, cross-section area, $A_{Si} = A_{S2}$ (Fig. 26) =
3 mm (half of inter-electrode distance) x 100 mm (width of each electrode) =
300 mm².

Linear velocity of the vertically ascending flowing water: $V = 52,000 \text{ mm}^3 / \text{sec}$
 $300 \text{ mm}^2 = 173.3 \text{ mm/sec}$.

Duration of the water treatment cycle: $t = 300 : 173 = 1.73 \text{ sec}$.

These parameters are synchronized for all four electrodes and all four flows (Fig. 26).

Conductivity of the input water solution: 1600 μS .

Hardness of the input water solution ~ 200 mg/l.

As shown in Fig. 26, the electrodes and two power supply units (m-PSU and s-PSU) are connected in parallel. The master power supply unit (m-PSU) parameters are set at 60 V and 50 A (max). The rate of the pump is 3 m³ / hr. The pump is switched on and the water flow is set at 0.75 m³ / hr. The flow sensor

(32) is set to the lowest limit of 5001/hr.

The master power supply unit (m-PSU) voltage and current parameters are set according to automatic feedback, at values of 46 V and 41 A, respectively. The programmable logic controller (PLC) synchronizes these master power supply unit parameters with the slave power supply unit (s-PSU). Based on the parallel connection of the master and slave power supply units (m-PSU and s-PSU), one electrode receives $41 \times 2 = 82$ A : 4 = 20.5 A, with a current density of 20.5 A per $3 \text{ dm}^2 = 6.83 \text{ A} / \text{dm}^2$. Current density at the anode is $683 \text{ A} / \text{m}^2$. Range of current variation is $\sim 39 - 42$ A.

The programmable logic controller (PLC) synchronizes the master and slave power supply units (m-PSU and s-PSU) with these parameters within 0.1 sec, such that the difference in current between the master and slave power supply units does not exceed 0.1 A.

Water Treatment Capacity

General capacity: $82 \text{ A} \times 46 \text{ V} = 3772 \text{ Watt}$

Capacity per electrode: 943 Watt

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Capacity per dm of electrode surface area: 314.3 Watt.

Capacity of all the four electrodes is synchronized with a range of variation of $\pm 7.1\%$ of the steady-state values.

Result: Input: 57.5 mg/l Cu. Output: cathode - 0.23 mg/l Cu.

The synchronized operation prevents secondary electrochemical processes from taking place during the time the water solution flows in the inter-electrode space.

30 Characteristic of secondary electrochemical processes is intensive generation of gas(es). Synchronized operation of the electrochemical reactor (ECR) and the energy supply mechanism (ESM) also stabilizes the dynamics of elementary electrochemical reactions, thereby preventing breaking symmetry of molecules in the flowing water solution, such as the process of asymmetric dissociation of the type: $\text{H}_2\text{O} \rightarrow \text{OH} + \text{H}_2 \text{ (g)}$.

Hydraulics of the Casing (Housing) of the Electrochemical Reactor

(ECR)

Immediately following are listed the main characteristics, features, conditions, and 5 operating parameters, of the hydraulics of the casing (housing) of the electrochemical reactor (ECR), with reference to Figs. 26, 2', and 3'.

—Two equivalent symmetrically identical channel systems of vertical input (supply) and output (discharge) channels.

—At points where entries of supply channels and exits of discharge channels 10 come together, especially seen in Figs. 2' and 3', there is a vertical “prismatic” type of geometrical water treatment chamber. This water treatment chamber is hydraulically connected with supply channels in its lower part and with discharge channels in its upper part.

—All the supply channels have identical cross-section area at homologous 15 points.

—All the discharge channels have identical cross-section area at homologous points.

—In each channel system, supply channels are placed on one side of the vertical water treatment chamber, the channels are adjacent and have a common 20 partition wall with openings in the lower and the upper parts communicating with the channels. In the lower part of the electrochemical reactor casing, the two channel systems are separated along the axis of symmetry by a wall, such that the wall has a stabilizing and leveling opening which connects the channel systems, and the diameter of the opening is significantly smaller than the cross section of the supply 25 channels.

Detailed Description of Electro-hydrodynamic Synchronization

During normal operation, each of the operating parameters (voltage, current, and power) generated by the energy supply mechanism (ESM) and supplied to the electrochemical reactor (ECR) changes as a direct consequence of treating the water 30 by the electrochemical reactions taking place inside the working chambers of the electrochemical reactor (ECR). The overall objective of the

synchronized operation of the ESM - ECR is to provide and maintain, in a stable manner, a high quality of the treated water output from the electrochemical reactor (ECR). This is accomplished by highly controlling and regulating, in a synchronized manner, the electrical operating parameters of voltage, current, and power, and variations thereof, generated by the energy supply mechanism (ESM) and supplied to the electrochemical reactor (ECR), during the water treating cycle.

Figs. 27 - 30 are schematic diagrams each illustrating a different exemplary specific preferred embodiment of the configuration (parallel or series) of the electrical connections of the power supply units (PSUs: master power supply unit (m-PSU) and slave power supply unit (s-PSU)) of the energy supply mechanism (ESM), relative to a different exemplary specific preferred embodiment of the configuration (parallel or 10 series) of the electrical connection of the two electrodes in each electrode cartridge or cell (C1) and (C2) positioned in a corresponding working chamber 8 and 5, respectively, of the electrochemical reactor (ECR), required for synchronized operation.

In each of Figs. 27 - 30, the terms 'FVF', 'SVF', 'FCF', and 'SCF', refer to fast 15 voltage feedback, slow voltage feedback, fast current feedback, and slow current feedback, respectively. Each of these terms is appropriately described below when further describing structure (electrical configuration), function, and synchronized operation, of the energy supply mechanism (ESM). Additionally, in each of Figs. 27-30, the letter “w” accompanied by an arrow indicates direction of the water flowing 20 through the inter-electrode space in each working chamber 8 and 5, or through the inter-electrode cell space, of the electrochemical reactor (ECR).

Figs. 31 and 32 are schematic diagrams illustrating an exemplary preferred embodiment of the voltage sensor (VS), hereinafter, referred to as the voltage sensor/stabilizer (VS), and of the current sensor (CS), hereinafter, referred to as the 25 current sensor/stabilizer (CS), respectively, and the 'functional' relation of each to the programmable logic controller (PLC), of the energy supply mechanism (ESM) of Figs. 27 - 30.

Included in each of Figs. 27 - 30, are the equations relating the voltage, $V(vs)$, sensed by the voltage sensor/stabilizer (VS), to the voltages, $V(PS1)$, $V(PS2)$, $V(C1)$,

and $V(c2)$, of the power supply units (PSUs: master power supply unit (m-PSU or psl) and slave power supply unit (s-PSU or ps2), respectively) of the energy supply mechanism (ESM), and of the electrode cells ((C1) and (C2), respectively) of the electrochemical reactor (ECR), respectively, during synchronized operation. Also included in each of Figs. 27 - 30, are the equations relating the current, $I(cs)$, sensed by the current sensor/stabilizer (CS), to the current, $I(psl)$, $I(ps2)$, $I(cl)$, and $I(c2)$, of the power supply units (PSUs: master power supply unit (m-PSU or psl) and slave power supply unit (s-PSU or ps2), respectively) of the energy supply mechanism (ESM), and of the electrode cells ((C1) and (C2), respectively) of the electrochemical 5 reactor (ECR), respectively, during synchronized operation.

The energy supply mechanism (ESM), via the programmable logic controller (PLC) automatically controlling the master power supply unit (m-PSU) for operating on and synchronizing with the slave power supply unit or units (s-PSU or s-PSUs, respectively), operates according to three synchronizable criteria, associated with 10 operation of the electrochemical reactor (ECR), for establishing, maintaining, and when appropriate, for re-establishing, a steady-state mode of synchronized operation:

1. Maximal accumulated charge (potential) on the active functional surface of each electrode in relation to instantaneous conductivity of the water flowing through and treated inside the electrochemical reactor (ECR).
2. Maximal current density on the active functional surface of each electrode in relation to instantaneous conductivity of the water flowing through and treated inside the electrochemical reactor (ECR).
3. Maximal use of the area of the active functional surface of each electrode while maintaining maximal values of current density.

Hence, the main purpose of the stable and integrated synchronized operation is to maximize use, and therefore, efficiency, of the energy generated by the energy supply mechanism (ESM) and supplied to the electrochemical reactor (ECR), in particular, the electrode cells and electrodes therein, for treating the flowing water. This is accomplished by maximizing use of active capacity of all the power supply 25 units (PSUs), while there

is continuously changing values of the parameters (conductivity, linear velocity, volumetric flow rate, chemical concentrations, temperature, and gradients thereof) of the water flowing through and treated inside the electrochemical reactor (ECR). By achieving this, following a minimal residence time of the water flowing through and treated inside the electrochemical reactor 30 (ECR), there is obtaining maximal concentrations of oxidants and coagulants in the treated flowing water exiting the electrochemical reactor (ECR).

For implementing the above described steady-state mode, and, non-steady- state or transient mode, of synchronization, the master power supply unit (m-PSU) operates as part of a feedback loop, as shown in Figs. 27- 30, receiving instructions fed back by the programmable logic controller (PLC). The result of this feedback process is to achieve operating conditions characterized by stable voltage and stable current generated by both the master and slave power supply units (m-PSU and s- PSU), and supplied to the electrochemical reactor (ECR), while the water flows 5 through and is treated inside the electrochemical reactor (ECR).

Via feedback information continuously supplied by the programmable logic controller (PLC), the master power supply unit (m-PSU), instantaneously reacts to changes in total electrical resistance defined by the combination of (i) the electrical resistance of the electrical wires connecting the power supply units (PSUs) to the 10 electrodes in the electrochemical reactor (ECR), (ii) the electrical resistance of the electrodes in the electrochemical reactor (ECR), and (iii) the electrical resistance, in the form of conductivity, of the water flowing through and treated inside the electrochemical reactor (ECR).

With reference to Figs. 27 - 32, the master power supply unit (m-PSU) reacts 15 to a spontaneous or instantaneous change in the electrical resistance (conductivity) of the water flowing through and treated inside the electrochemical reactor (ECR) in two stages. In the first stage, there is checking (by comparing (PLC) output and input voltages, via the voltage sensor/stabilizer element (VS)), and if needed, changing (via the voltage sensor/stabilizer element (VS)), the maximal value of voltage, in 20 accordance with a steady-state mode, or, non-steady-state or transient mode, of

synchronized operation (according to the order of magnitude of the spontaneous or instantaneous change (within about (+ / -) 1 % of the steady-state range, or within about (+ / -) 7 - 10 % of the steady-state range, respectively) of the electrical resistance (conductivity) of the water flowing through and treated inside the 25 electrochemical reactor (ECR)), with the slave power supply units (s-PSUs), via the programmable logic controller (PLC). Checking and changing are performed until the maximum possible voltage is supplied by the energy supply mechanism (ESM) to the electrodes in the electrode cells ((C1) and (C2)) in the electrochemical reactor (ECR).

Immediately following the first stage, the master power supply unit (m-PSU) 30 automatically switches to the second stage of checking and possible changing. In the second stage, there is checking (by comparing (PLC) output and input currents, via the current sensor/stabilizer element (CS)), and if needed, changing (via the current sensor/stabilizer element (CS)), the maximal value of current, in accordance with a steady-state mode, or, non-steady-state or transient mode, of synchronized operation (according to the order of magnitude of the spontaneous or instantaneous change (within about (+ / -) 1 % of the steady-state range, or within about (+ / -) 7 - 10 % of the steady-state range, respectively) of the electrical resistance (conductivity) of the water flowing through and treated inside the electrochemical reactor (ECR)), with the 5 slave power supply units (s-PSUs), via the programmable logic controller (PLC).

Checking and changing are performed until the maximum possible current is supplied by the energy supply mechanism (ESM) to the electrodes in the electrode cells ((C1) and (C2)) in the electrochemical reactor (ECR).

During ordinary operation of the electrochemical reactor (ECR) and of the 10 energy supply mechanism (ESM), these two stages of checking and possible changing, of the operating voltage and/or operating current, along with completing the steady-state mode, or, non-steady-state or transient mode, of synchronized operation of the master and slave power supply units (m-PSU and s-PSUs), rapidly take place within a relatively short time period of on the order of less than one second. Each change in total electrical resistance causes immediate reaction by the master power supply unit (m-PSU), along with an instantaneous steady-state mode, or, non-steady-state or

transient mode, of synchronized operation of the master power supply unit (m-PSU) with each slave power supply unit (s-PSU). During operation of the electrochemical reactor (ECR), electrical resistance of the connecting wires and of 20 the electrodes remain essentially constant. Any change in total electrical resistance is essentially determined by a change in the dynamic characteristics, in terms of the parameters (conductivity, linear velocity, volumetric flow rate, chemical concentrations, temperature, and gradients thereof) of the water flowing through and treated inside the electrochemical reactor (ECR). Accordingly, the above two stages 25 of checking and possible changing, of the maximal values of voltage and current, along with completing the steady-state mode, or, non-steady-state or transient mode, of synchronized operation of the master and each slave power supply unit (m-PSU and s-PSU), result in utilizing the maximum possible capacity of the electrodes for treating the flowing water. This provides conditions for increasing the specific 30 concentrations of oxidants and coagulants, which in turn translates to increasing the overall efficiency of the electrochemical reactor (ECR) for treating the flowing water.

Referring again to Figs. 27 - 30, during synchronized operation of the energy supply mechanism (ESM) and of the electrochemical reactor (ECR), the voltage sensor/stabilizer (VS) and the current sensor/stabilizer (CS) sense and register the operating voltage and current of the electrodes in the electrode cells ((C1) and (C2), respectively) of the electrochemical reactor (ECR). Then, the voltage sensor/stabilizer (VS) and the current sensor/stabilizer (CS) simultaneously send appropriately timed fast feedback signals, FVF and FCF, respectively, to the power 5 supply units (PSUs: master power supply unit (m-PSU or ps1) and slave power supply unit (s-PSU or ps2), respectively).

The fast voltage feedback signal, FVF, and the fast current feedback signal, FCF, perform two important functions: (1) for preventing undesirably large (for example, larger than 7 - 10 %) and potentially system damaging changes in the 10 voltage and current, and therefore, for preventing undesirably large and potentially system damaging changes in the power, sent from the energy supply mechanism (ESM) to the electrochemical reactor (ECR), and (2) for stabilizing transmission of the

operating parameters of voltage, current, and power, throughout the entire (ESM)

- (ECR) electronic circuit. This accounts for the stabilizing affect or function of the 15 voltage sensor/stabilizer (VS) and of the current sensor/stabilizer (CS).

Immediately following completion of the fast feedback process, the voltage sensor/stabilizer (VS) and the current sensor/stabilizer (CS) send appropriately timed slow feedback signals, SVF and SCF, respectively, to the programmable logic controller (PLC). According to the values of the SVF and SCF feedback signals, the 20 programmable logic controller (PLC) then performs the synchronized operation and regulation of the power supply units (PSUs: master power supply unit (m-PSU or ps1) and slave power supply unit (s-PSU or ps2), respectively), as previously described above.

The fast feedback signals, FVF and FCF, are sent to the power supply units 25 (PSUs), in approximately half ($1/2$) the time that the slow feedback signals, SVF and SCF, are sent to the programmable logic controller (PLC). The (ESM) electronic circuit is intentionally designed and constructed such that the lengths of the signal paths from the voltage sensor/stabilizer (VS) and the current sensor/stabilizer (CS) to the power supply units (PSUs) are substantially shorter than the lengths of the signal 30 paths to the programmable logic controller (PLC), for performing the two functions stated above, thereby preventing undesirable and potentially costly “downtime” during the overall water treatment process.

Reference is again made to Figs. 31 and 32, schematic diagrams illustrating an exemplary preferred embodiment of the voltage sensor/stabilizer (VS), and of the current sensor/stabilizer (CS), respectively, and the “functional” relation of each to the programmable logic controller (PLC), of the energy supply mechanism (ESM) of Figs. 27 - 30. As shown in Figs. 31 and 32, each of the voltage sensor/stabilizer (VS), and of the current sensor/stabilizer (CS), respectively, includes operative connections

I

5 of an input rectifier 1', a high-frequency power converter 2', an output rectifier 3', and a comparator 4\ Comparator 4' is operatively connected to the programmable logic controller (PLC). In Fig. 32, R corresponds to a resistance or load in the

circuit.

Each of the voltage sensor/stabilizer (VS), and of the current sensor/stabilizer (CS), respectively, generates and feeds back the previously described slow feedback signals, 10 SVF and SCF, respectively, to the programmable logic controller (PLC).

During operation of the voltage sensor/stabilizer (VS), as indicated in Fig. 31, an operator of the water treatment system selects or assigns an assigned voltage, $U_{assigned}$, to the programmable logic controller (PLC). The operating voltage,

U_{oper} , is a function of the assigned voltage, $U_{assigned}$. The output voltage, U_{out} , is a function of the operating voltage, U_{oper} , and consequently, the output voltage. U_{out} , is a function of the assigned voltage, $U_{assigned}$. Comparator 4' compares the operating voltage, U_{oper} , to the output voltage, U_{out} .

During operation of the current sensor/stabilizer (CS), as indicated in Fig. 32, an operator of the water treatment system selects or assigns an assigned current, $I_{assigned}$, to the programmable logic controller (PLC). The operating voltage, U_{oper} , (same as that existing in the voltage sensor/stabilizer (VS) circuit of Fig. 31) is a function of a comparison current, $I_{comparison}$, which in turn is defined by the difference between the assigned current, $I_{assigned}$, and the output current, I_{out} . The output current, I_{out} , is a function of the assigned current, $I_{assigned}$. Actual operating specifications and tolerances of each of the separate components, input rectifier 1', high-frequency power converter 2', output rectifier 3', comparator 4', and resistance or load R , of each of the voltage sensor/stabilizer (VS), and of the current sensor/stabilizer (CS), respectively, shown in Figs. 31 and 32, are selected primarily according to the output current, I_{out} , and secondarily according to the output voltage, U_{out} , since current density along the surface area of the electrodes is the controlling parameter during operation of the electrochemical reactor (ECR) for treating the water. Moreover, even though each of these separate components of the voltage sensor/stabilizer (VS) and of the current sensor/stabilizer (CS) are well known about and used in the prior art, and readily available in the marketplace, their combination is customized for particularly performing the above described sensing,

stabilizing, and feedback, functions, as part of the energy supply mechanism (ESM).

The programmable logic component (PLC) of the energy supply mechanism (ESM) is a logic component which has built-in pre-designed logic, which operates or 5 performs according to particular algorithmic input parameters, output parameters, and commands, for the purpose of operating and regulating the overall (ESM) -(ECR) circuit, for example, based on the operating parameters of voltage, current, and power, and time of response to changes in these parameters. The programmable logic component (PLC) is a well known and used electronic component which is readily 10 available on the marketplace. Once obtained, the programmable logic component (PLC) is programmed according to the specific requirements of the user or operator, for example, in the present case, for providing synchronized operation of the (ESM) - (ECR) circuit, as part of a more encompassing water treatment system.

It should be understood that the invention is defined by the claims that follow, 15 and is not limited by the details of the illustrative embodiments.

Table 1: Results of Comparative Tests of Various Cassettes

Source	Conne c tion	Cassette type	Water through -put	Cur rent	Vol tage	Power	pH			Condu c tivity			Cu mg/l			Date
A/V		-	l/h	A	V	kW	In put	An ode	Ca tho	Input	An ode	Ca thode	Input	An ode	Ca thod	
50/50	Parallel	Anode Al Cathode Al No Mem-brane	2000	96	25	2.496	8.5	8.5	9	1380	1470	1340	75 37.6	25 2	37.5 12.5	4.02
30/100	Parallel	Anode Al Cathode Al No Mem-brane	2000	56	24	1.344	9	8.5	9	1385	1390	1370	60 30	30 15	40 30	4.02
50/60	Parallel	Anode Steel Cathode Steel No Mem-brane	2000	96	24	2.304	8.5	8.5	9	1497	1510	1345	50 30	37.5 20	40 25	4.02
30/100	Parallel	Anode Steel Cathode Steel No Mem- brane	2000	56	14	0.784	8.5	8.5	9	1520	1540	1412	37.5 30	25 20	25 20	4.02
50/60	Parallel	Anode Ti Cathode Ti No	2000	96	29	2.784	9	9	9.5	1670	1725	1625	70 53	45 15	65 25	7.02

30/100	Parallel	Anode Ti Cathode Ti No Mem-brane	2000	56	21	1.176	9	9	9.5	1655	15 66	1566	60 30	50 18	60 37.5	7.02
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Table 2: Results of Comparative Tests of Various Cassettes

Source	Connection	Cassette type	Water through-put l/h	Current A	Voltage V	Power kW	pH Input				Conductivity Input				Cu mg/l Input				Date
A/V								Anode	Ca thod		Anode	Ca thod				Anode	Ca thod		
50/60	Parallel	Anode Al Cathode Al With Membrane	2000	35	120	4.32	9	9	9.5	1819	1815	1755	75 37.5	67.5 20	67.5 37.5				5.02
30/100	Parallel	Anode Al Cathode Al With Membrane	2000	52	65	4.42	9	8.5	9	1520	1565	1432	67.5 25	37.5 25	50 20				4.02
30/100	Parallel	Anode Steel Cathode Steel	2000	52	65	4.42	9	9	9.5	1795	1602	1743	75 37.5	37.5 30	67.5 30				5.02
30/100	Parallel	Anode Al Cathode Al With Membrane	2000	50	55	4.25	9	9	9.5	1750	1013	1764	35 30	50 20	50 20				5.02

Table 3: Test Bench Results

Cassette type	Water flow	Current	Voltage	Power	pH			Conduc			Cu mg/l			Date
	l/h	A	V	kW	In put	An ode	Ca thod	Input	An ode	Ca thod	Input	An ode	Ca thod	
Anode A1 Cathode A1 With Membrane	2000	36	120	4.32	9	9	9.5	1819	181	1755	75* - 37.5**	67.5 - 20	67.5 - 37.5	5.02
Anode A1 Cathode A1 With Membrane	2000	52	85	4.42	9	8.5	9	1520	156	1432	67.5 - 25	37.5 - 25	50 - 20	4.02
Anode A1 Cathode SS With Membrane	2000	52	85	4.42	9	9	9.5	1795	180	1743	75 - 37.5	67.5 - 30	67.5 - 30	5.02
Anode A1 Cathode SS With Membrane	2000	50	85	4.25	9	9	9.5	1780	181	1764	75 - 30	50 - 20	50 - 25	5.02

* - total copper concentration

** - copper concentration after filtration

CLAIMS

I claim:

1. A power control for an electrically powered water treatment apparatus having electrode cells, comprising:
 - a master power supply unit having a control input;
 - a slave power supply unit having a control input;
 - a current sensor adapted to measure the electrical current flowing through the cells of the water treatment apparatus;
 - a voltage sensor adapted to measure the voltage applied to the cells of the
10 water treatment apparatus;
 - a PLC having inputs from said current sensor and said voltage sensor and outputs for said master and slave power supply units;
 - wherein, said PLC is programmed so as to be able to maximize the electrical power applied to the cells without overheating.
2. The power control of claim 1, wherein the cells are driven in a series circuit.
3. The power control of claim 1, wherein the cells are driven in a parallel circuit.
4. The power control of claim 1, wherein the cells are driven in a psuedo-
20 parallel circuit, wherein the cells are connected in series and the current regulated so as to simulate parallel operation.

References, patent and license information

Appendix 1

United States Patent
Tamarkin

5,658,450
August 19, 1997

Method of and device for industrial waste water treatment

Abstract

Waste **water** is purified by passing through a vessel in which small particles of insoluble cathodes interact with anodes to form galvanic couples. During this process, chemical reduction of ions of **heavy metals in the water** occurs by ions and hydroxides formed during **electrochemical** dissolution of anodes. The hydroxides are an excellent coagulating agent which absorbs impurities contained in the **water**. Pressurized air can saturate the waste **water** simultaneously with passing through the vessel with anodes in order to produce process floatation using hydroxides as coagulant. The temperature of the waste **water** can be increased in order to intensify the process of **treatment**.

Appendix 2

United States Patent
Khudenko , et al.

7,553,418
June 30, 2009

Method for water filtration

Abstract

This is a method of filtration of a liquid comprising steps of sequential filtration of said liquid through at least one deep bed medium producing at least one first filtrate followed by at least one membrane medium filtration producing at least one second filtrate, wherein said membrane medium is at least periodically within said deep bed media. Many types of deep bed and membrane media can be used. The domain of using contact clarification (direct filtration) can be expanded towards greater solids concentration. Operation and backwash, is simplified, continuous filtration becomes possible. **Water** can be **water** from natural source **water**, process **water**, wastewater, aqueous or non-aqueous suspensions, emulsions, solutions. **Treatment** can include mechanical interception of suspended particles, chemical, physical chemical, **electrochemical**, and biological processes. In **water** and wastewater processing, control over suspended solids, BOD, COD, nitrogen and phosphorus compounds, bacteria and viruses, **heavy metals**, color, and other constituents can be dramatically improved as compared to conventional processes. The method can be accommodated in new and modified existing **treatment** systems.

Appendix 3

United States Patent
Hale , et al.

10,745,300
August 18, 2020

Configuration for electrochemical water treatment

Abstract

An **electrochemical water treatment** apparatus includes a **treatment** chamber formed by at least one wall and having an opening formed along the side for substantially the length of the **treatment** chamber, with a mounting plate applied to the opening. A set of cathodes and anodes are mounted to the mounting plate and positioned inside the chamber, each of the anodes having at least one cathode positioned on each of the two sides of the respective anode. At least two anode bus bars and two cathode bus bars are provided, each bus bar connectable to the power supply and connected to the respective electrodes near a respective end of the electrodes. An inlet adapter has a smaller cross sectional area at the first end connected to the **treatment** chamber inlet end, and a larger cross sectional area at the opposite end connected to the source of **water** to be treated. An outlet adapter has a smaller cross sectional area at the first end connected to the **treatment** chamber outlet end, and a larger cross sectional area at the second end connected to the destination for the treated **water**.

Appendix 4

United States Patent
Wang , et al.

9,868,659
January 16, 2018

Subsurface water purification method

Abstract

A method of producing purified **water** in a subsurface environment is provided in which ambient subsurface source **water** is introduced into and through one or more ultrafiltration membrane units of a subsurface **water treatment** system and producing thereby an ultrafiltrate substantially free of solid particulates having a largest dimension greater than 0.1 microns. An **electrochemical** unit in fluid communication with at least one ultrafiltration membrane unit provides an antifoulant solution. An ultrafiltrate-rich backwash fluid and at least a portion of the antifoulant solution are delivered to at least one non-producing ultrafiltration membrane unit during a backwash cycle. A flux of source fluid through each of the ultrafiltration membrane units of less than thirty gallons per square foot per day limits the need for backwash cycles. A reduction in the number of backwash cycles enhances system autonomy and useful life, and limits the need for intervention for maintenance and component replacement.

Appendix 5

United States Patent
Wilkins , et al.

8,114,260
February 14, 2012

Water treatment system and method

Abstract

A **water treatment** system provides treated or softened **water** to a point of use by removing a portion of any hardness-causing species contained in **water** from a point-of-entry coming from a **water** source, such as municipal **water**, well **water**, brackish **water** and **water** containing foulants. The **water treatment** system typically treats the **water** containing at least some undesirable species before delivering the treated **water** to a point of use. The **water treatment** system has a controller for adjusting or regulating at least one operating parameter of the **treatment** system or a component of the **water treatment** system to optimize the operation and performance of the system or components of the system. A flow regulator regulates a waste stream flow to drain and can be operated to recirculate fluid through electrode or concentrating compartments of an **electrochemical** device and can be opened and closed intermittently according to a predetermined schedule or based on an operating parameter of the **water treatment** system. The flow regulator can also be charged so that ionic species can be generated in the surrounding fluid, which, in turn, can lower the pH of the surrounding fluid.

Appendix 6

United States Patent
Jha , et al.

8,377,279
February 19, 2013

Water treatment system and method

Abstract

A **treatment** system provides treated or softened **water** to a point of use by removing at least a portion of any undesirable species contained in **water from a water** source. The **treatment** system can be operated to reduce the likelihood of formation of any scale that can be generated during normal operation of an **electrochemical** device. The formation of scale in the **treatment** system, including its wetted components, may be inhibited by reversing or substituting the flowing liquid having hardness-causing species with another liquid having a low tendency to produce scale, such as a low LSI **water**. Various arrangements of components in the **treatment** system can be flushed by directing the valves and the pumps of the system to displace liquid having hardness-causing species with a liquid that has little or no tendency to form scale.

Appendix 7

United States Patent
Freydina , et al.

8,585,882
November 19, 2013

Systems and methods for water treatment

Abstract

Electrochemical devices and methods for **water treatment** are disclosed. An electrodeionization device (100) may include one or more compartments (110) containing an ionselective media, such as boron-selective resin (170). Cyclic adsorption of target ions and regeneration of the media in-situ is used to treat process **water**, and may be driven by the promotion of various pH conditions within the **electrochemical** device.

Appendix 8

United States Patent
Wilkins , et al.

8,658,043
February 25, 2014

Water treatment system and method

Abstract

A **water treatment** system provides treated **water** to a point of use by removing at least a portion of any hardness-causing species contained in **water from a water** source, such as municipal **water**, well **water**, brackish **water** and **water** containing foulants. The **water treatment** system typically receives **water from the water** source or a point of entry and purifies the **water** containing at least some undesirable species before delivering the treated **water** to a point of use. The **water treatment** system has a pressurized reservoir system in line with an **electrochemical** device such as an electrodeionization device. The **water treatment** system can have a controller for adjusting or regulating at least one operating parameter of the **treatment** system or a component of the **water treatment** system. The **electrochemical** device can be operated at a low current and low flow rate to minimize **water** splitting or polarization, which minimizes scale formation.

Appendix 9

United States Patent
Schwartzel , et al.

8,999,173
April 7, 2015

Aqueous treatment apparatus utilizing precursor materials and ultrasonics to generate customized oxidation-reduction-reactant chemistry environments in electrochemical cells and/or similar devices

Abstract

An electrochlorination and **electrochemical** system for the on-site generation and **treatment** of municipal **water** supplies and other reservoirs of **water**, by using a custom mixed oxidant and mixed reductant generating system for the enhanced destruction of **water** borne contaminants by creating custom oxidation-reduction-reactant chemistries with real time monitoring. A range of chemical precursors are provided that when acted upon in an **electrochemical** cell either create an enhanced oxidation, or reduction environment for the destruction or control of contaminants. Chemical agents that can be used to control standard **water** quality parameters such as total hardness, total alkalinity, pH, total dissolved solids, and the like are introduced via the chemical precursor injection subsystem infrequently or in real time based on sensor inputs and controller set points.

Appendix 10

United States Patent
Nyberg , et al.

9,090,493
July 28, 2015

Electrochemical ion exchange treatment of fluids

Abstract

A fluid **treatment** apparatus comprises an **electrochemical** cell having fluid orifices to receive input fluid and release output fluid, the input fluid having a first level of a microorganism. First and second electrodes are about a **water**-splitting membrane in the **electrochemical** cell. A valve controls the flow of fluid through fluid orifices of the **electrochemical** cell. A power supply supplies a current to the first and second electrodes. A control module comprises program code to operate the valve to flow the input fluid into a fluid orifice of the **electrochemical** cell and provide a residence time of the fluid in the cell of at least 0.05 minutes, while controlling the power supply to supply to the first and second electrodes, a current having a current density of from about 0.01 to about 20 mA/cm².

Appendix 11

United States Patent
Li , et al.

9,221,696
December 29, 2015

Wastewater treatment process by electrochemical apparatus

Abstract

A wastewater **treatment** process by an **electrochemical** apparatus, said apparatus having at least an **electrochemical** electrode (30), and said **electrochemical** electrode (30) having suitable electrode plates comprises the following steps: passing high concentration wastewater containing undesirable solutes through at least one **electrochemical** electrode (30) to which a DC electrical current is applied to destroy the undesirable solutes in the **water** intake, so as to output **water** having a lower concentration of the undesirable solutes; the DC current applied to the **electrochemical** electrode (30) comprises at least a constant potential difference stage exerted on both ends of the **electrochemical** electrode (30), and followed by a constant current stage through the **electrochemical** electrode (30).

Appendix 12

United States Patent
Legzdins

9,440,866
September 13, 2016

Efficient treatment of wastewater using electrochemical cell

Abstract

An efficient method and system for the **electrochemical treatment** of waste **water** comprising organic and/or inorganic pollutants is disclosed. The system comprises an electrolytic cell comprising a solid polymer, proton exchange membrane electrolyte operating without catholyte or other supporting electrolyte. The cell design and operating conditions chosen provide for significantly greater operating efficiency.

Appendix 13

United States Patent
Jha , et al.

9,574,277
February 21, 2017

Electrochemical water softening system

Abstract

Systems and methods for treating **water** are provided. The systems and methods may utilize an **electrochemical water treatment** device comprising ion exchange membranes. In certain systems and methods, a concentrate stream and a dilution stream may be in fluid communication with ion exchange membranes. The ion exchange membranes may be configured to provide a ratio of a pH of the concentrate stream and a pH of the dilution stream to be less than about 1.0. In some instances, the LSI of the concentrate stream may be less than or about 1.0. In certain instances, the **electrochemical water treatment** device does not require a reverse polarity cycle.

Appendix 14

United States Patent
Kim , et al.

9,963,363
May 8, 2018

Continuous flow-electrode system, and high-capacity power storage and water treatment method using the same

Abstract

The present invention uses the principles of **electrochemical** ion absorption (charging) and ion desorption (discharge), and relates to a continuous flow-electrode system, a high-capacity energy storage system, and a **water treatment** method using the same, in which high-capacity electric energy is stored as electrode materials of a slurry phase and electrolytes simultaneously flow in a successive manner within a fine flow channel structure formed on an electrode. More specifically, the present invention relates to a continuous flow-electrode system, an energy storage system, and a **water treatment** method, wherein electrode active materials consecutively flow in a slurry state whereby a high capacity is easily obtained without enlarging or stacking electrodes.

Appendix 15

United States Patent
Silver , et al.

9,963,790
May 8, 2018

Bio-electrochemical systems

Abstract

The present invention provides **bio-electrochemical** systems having various configurations for the **treatment of water**, wastewater, gases, and other biodegradable matter. In one aspect, the invention provides **bio-electrochemical** systems configured for treating wastewater while generating multiple outputs. In another aspect, the invention provides **bio-electrochemical** systems configured for improving the efficiency of electrodialysis removal systems. In yet another aspect, the invention provides bio-electro-chemical systems configured for use in banks and basins.

Appendix 16

United States Patent
Thomas

10,604,428
March 31, 2020

Waste water treatment

Abstract

A waste **water treatment** apparatus utilizing **electrochemical** technology. **Electrochemical** waste **water treatment** is based on the application of an electric field between an anode and a cathode to the waste **water**. The apparatus for waste **water treatment** comprise a channel extending through a housing between an inlet and an outlet and a **water treatment** zone between the inlet and outlet. The apparatus further comprise first and second spaced apart electrodes having working ends for treating waste **water in the treatment** zone, and an electrode feed arrangement for feeding the first and second electrodes towards the channel to control the spacing between the working ends of the first and second electrodes.

Appendix 17

United States Patent
Sasabe , et al.

10,815,134
October 27, 2020

Water treatment device

Abstract

The **water treatment** device according to the present disclosure includes: an **electrochemical** cell having electrodes including a positive electrode and a negative electrode, and a bipolar membrane; a tank; a power supply configured to apply power to the electrodes; a **water** circulation flow path having at least the tank and the **electrochemical** cell and through which **water** circulates; a circulation device configured to circulate **water in the water** circulation flow path; a raw **water** supply path configured to supply raw **water to the water** circulation flow path; and a control device. In performing **water** softening **treatment in the electrochemical** cell where power is applied to the electrodes so as to remove ions from raw **water** and soft **water** is produced, the control device drives the circulation device so as to circulate **water in the water** circulation flow path.

Appendix 18

United States Patent
Martikainen , et al.

10,604,427
March 31, 2020

Electrochemical reactor, an apparatus and a system for treating water, and a method for controlling a water treatment apparatus

Abstract

A **water treatment** apparatus includes an **electrochemical** reactor including a shell structure and a support structure for supporting the shell structure on a base. The support structure includes at least one support element supporting the shell structure from the ledge. A head room portion includes, within the inner space of the shell structure, at least one shelf for receiving and supporting at least one lug portion of at least one electrode plate for suspending the electrode plate. The shelf being located, when in use, preferably directly above the ledge.

Appendix 19

United States Patent
Sasabe , et al.

10,507,429
December 17, 2019

Electrochemical cell, water treatment device provided with same, and operating method for water treatment device

Abstract

An **electrochemical** cell according to the present disclosure includes a casing provided with an inflow port and an outflow port, a bipolar membrane laminated body in which two or more bipolar membranes are laminated so as to be opposed, electrodes disposed so as to sandwich the bipolar membrane laminated body, and a first diffusion member disposed between the inflow port and the bipolar membrane laminated body, and provided with through holes communicating between the inflow port and the bipolar membrane laminated body. The first diffusion member is formed such that each of the through holes provided in a peripheral edge portion has a larger opening area than an opening area of the through holes provided in a central portion. This can uniformize a flow of **water**, so that **water treatment** can be efficiently executed.

Appendix 20

United States Patent
Salokannel , et al.

10,329,173
June 25, 2019

System for treating water

Abstract

A system for treating **water** includes an **electrochemical water treatment** unit having a first self-supporting framework limiting a first inner space. An **electrochemical** reactor is arranged in the first inner space vertically below a first opening at a top side of the **electrochemical water treatment** unit. The system includes a maintenance unit having a second self-supporting framework limiting a second inner space. The maintenance unit includes a second opening in a bottom side. The maintenance unit is arranged above the **electrochemical water treatment** unit so that the first opening and the second opening are aligned. A hoist is moveably arranged along a rail structure at the top side of the maintenance unit.

Appendix 21

United States Patent
Martikainen , et al.

10,287,181
May 14, 2019

Electrochemical reactor for electrochemically treating water, a water treatment apparatus and use of such said electrochemical reactor

Abstract

An **electrochemical** reactor for electrochemically treating **water**, including a shell structure defining an inner space. The shell structure further includes an inlet portion having an inlet for conducting a **water** flow to the inner space, and a reactor chamber in flow connection with the inlet portion, and preferably with an outlet portion. The inlet is arranged such that the **water** flow to the inner space is directed away from the reactor chamber so as to cause the **water** flow to mix by forcing the **water** flow to change direction before entering the reactor chamber. A **water treatment** apparatus having such a reactor, and the use of such a reactor are also disclosed.

Appendix 22

United States Patent
Legzdins

10,266,429
April 23, 2019

Efficient treatment of wastewater using electrochemical cell

Abstract

An efficient method and system for the **electrochemical treatment** of waste **water** comprising organic and/or inorganic pollutants is disclosed. The system comprises at least first and second solid polymer electrolyte electrolytic cell stacks in which each cell comprises a solid polymer, proton exchange membrane electrolyte operating without catholyte or other supporting electrolyte. The first and second stacks differ either in construction or operating condition. The cell stack design and operating conditions chosen provide for significantly greater operating efficiency.

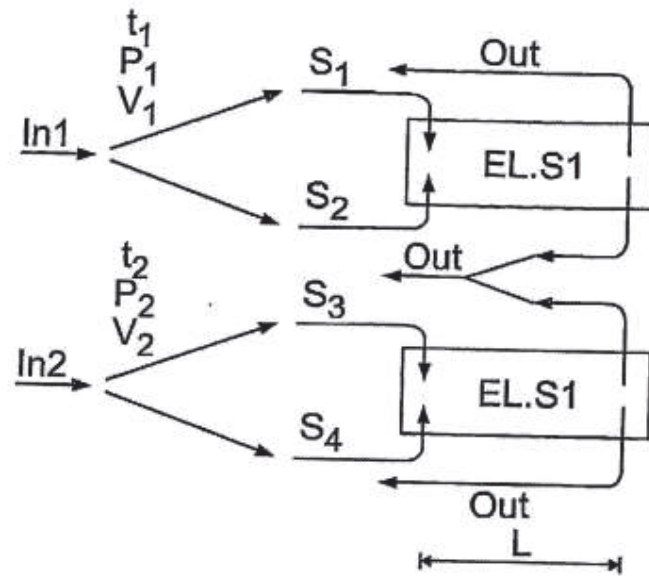
Appendix 23

United States Patent
Mehmi , et al.

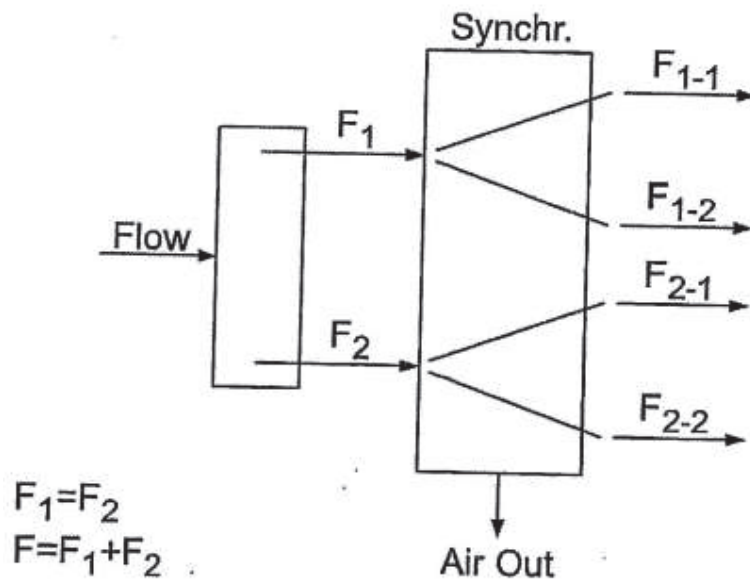
9,701,548
July 11, 2017

Abstract

Systems and methods for treating **water** are provided. The systems and methods may utilize an **electrochemical water treatment** device comprising ion exchange membranes. In certain systems and methods, a concentrate stream and a dilution stream may be in fluid communication with ion exchange membranes. The ion exchange membranes may be configured to provide a ratio of a pH of the concentrate stream and a pH of the dilution stream to be less than about 1.0. In some instances, the LSI of the concentrate stream may be less than or about 1.0. In certain instances, the **electrochemical water treatment** device does not require a reverse polarity cycle.



$L/V=T(\text{Const})$ for $S_1; S_2; S_3; S_4$
 In Sells S -S Time-Cost. for All Streams



$$F_1 = F_2$$

$$F = F_1 + F_2$$

$$F_{1-1} = F_{1-2} = F_{2-1} = F_{2-2} = F/4$$

FIG. 1

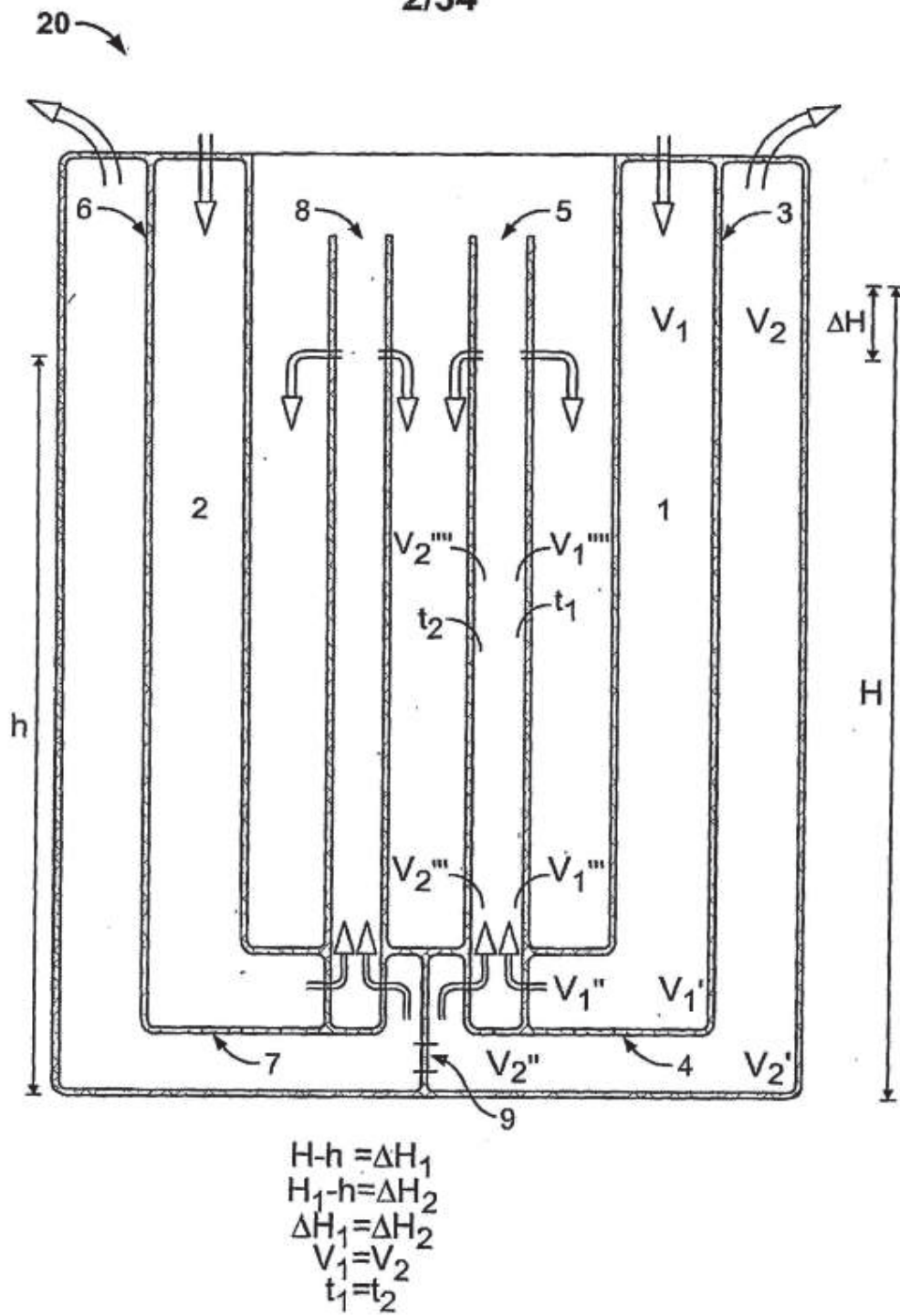


FIG. 2

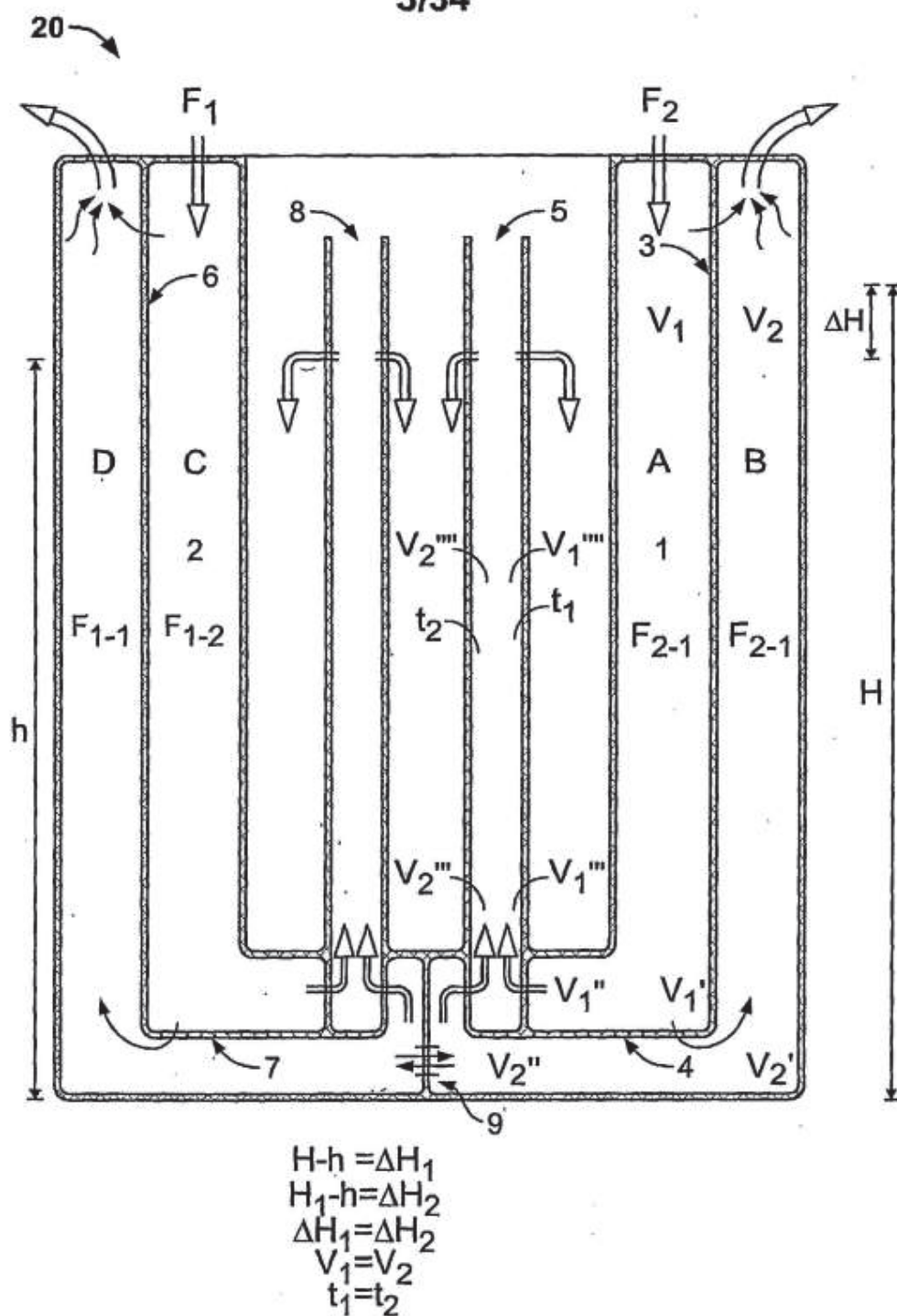


FIG. 2'

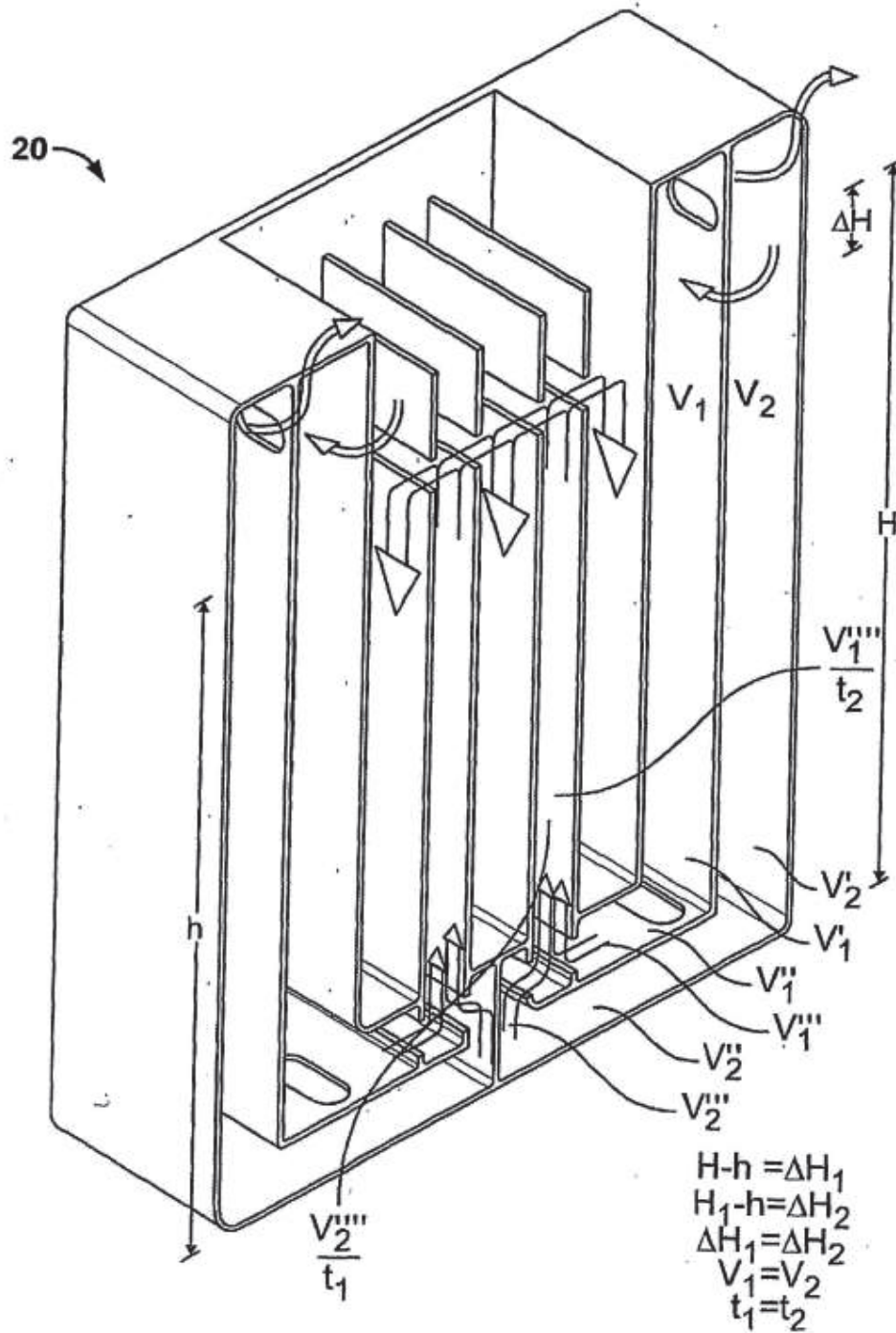


FIG. 3

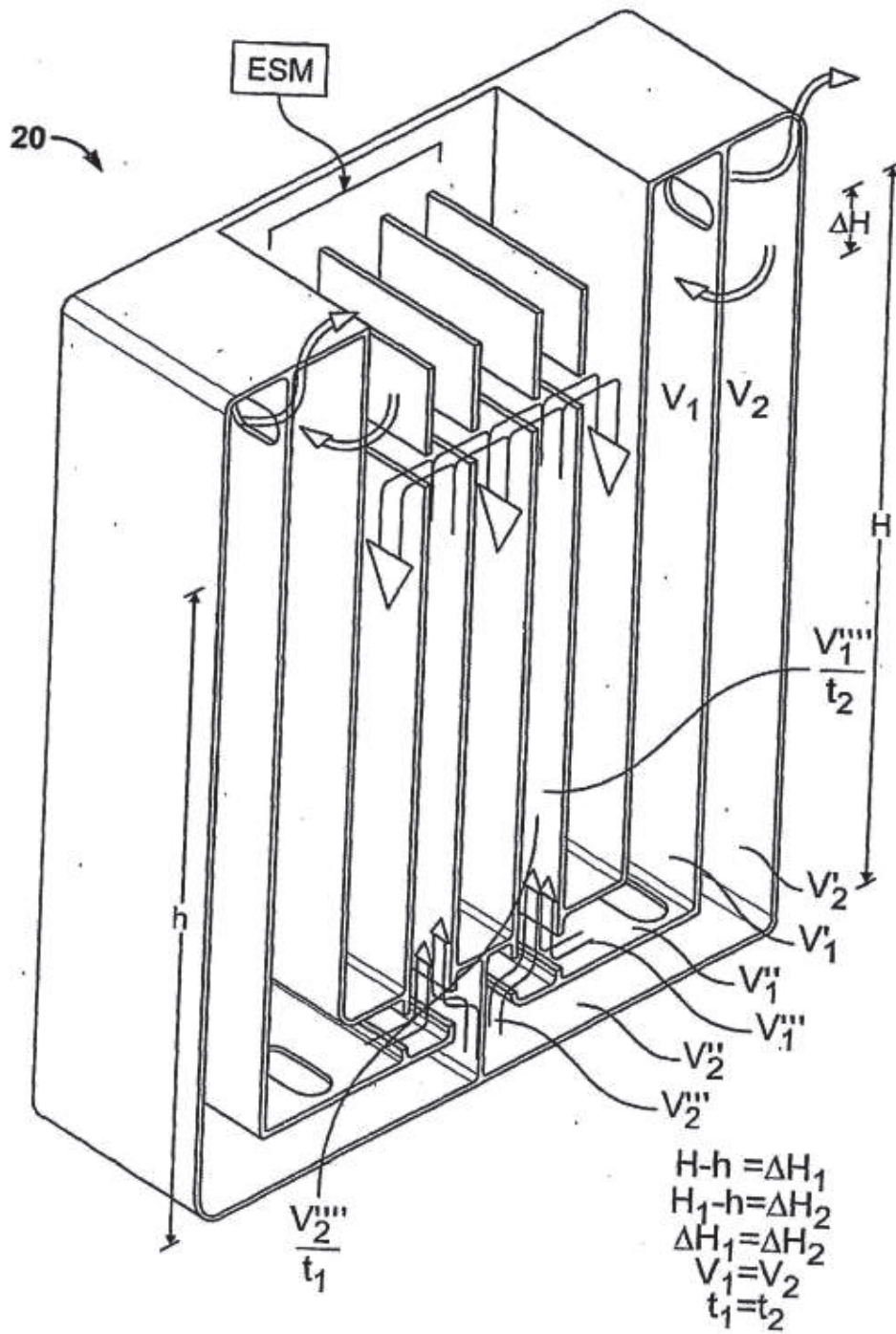


FIG. 3'

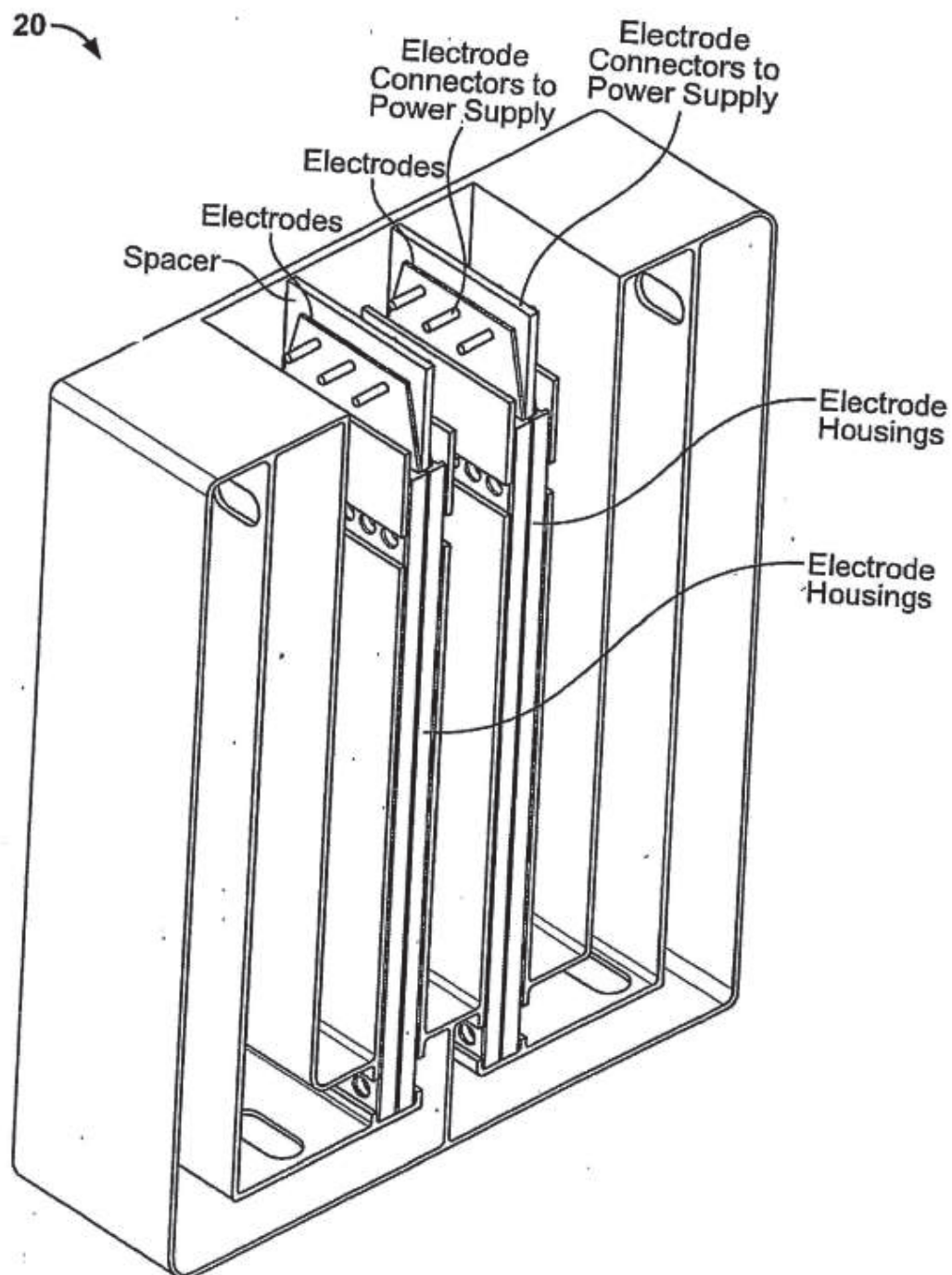


FIG. 4

7/34

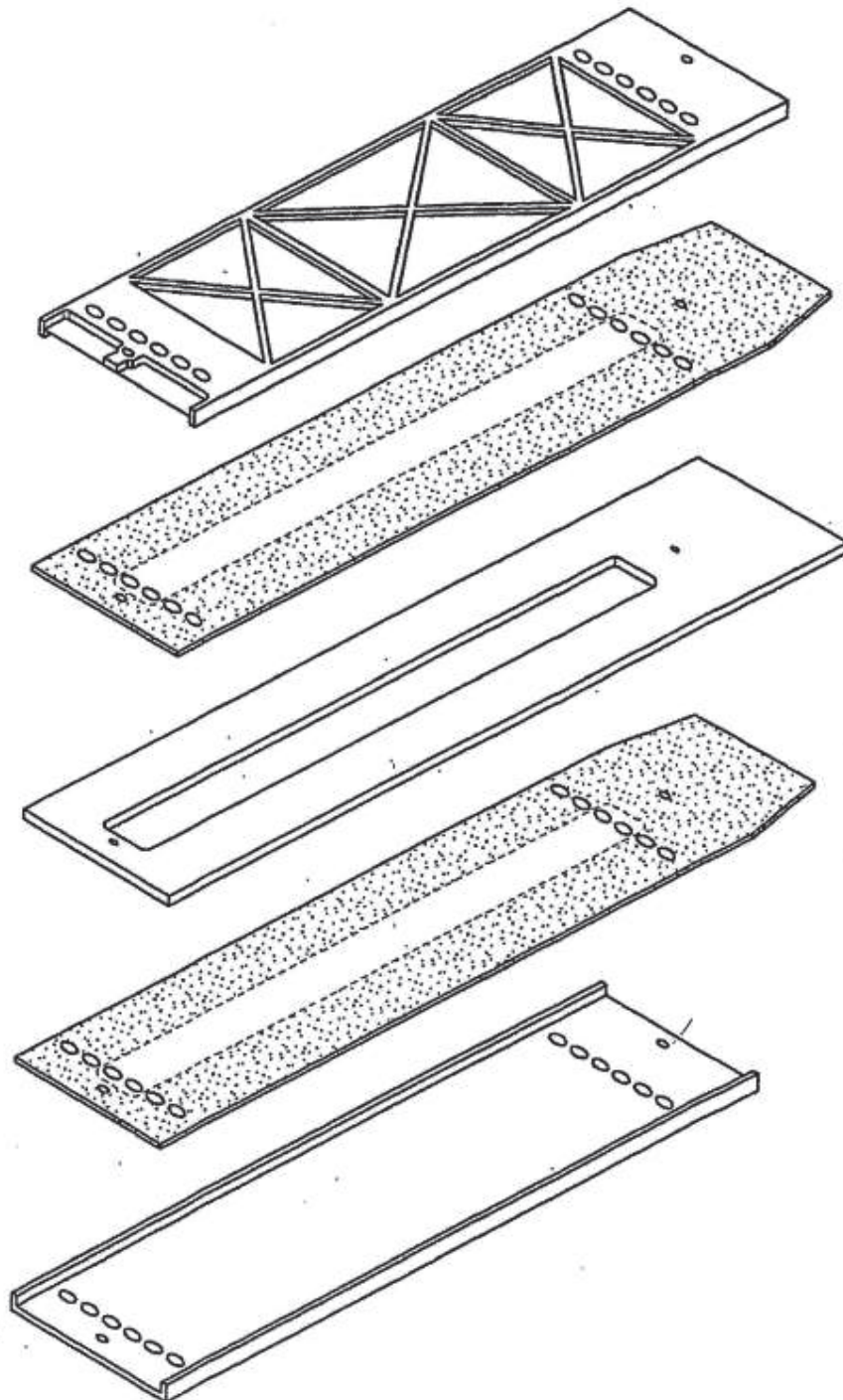


FIG. 5

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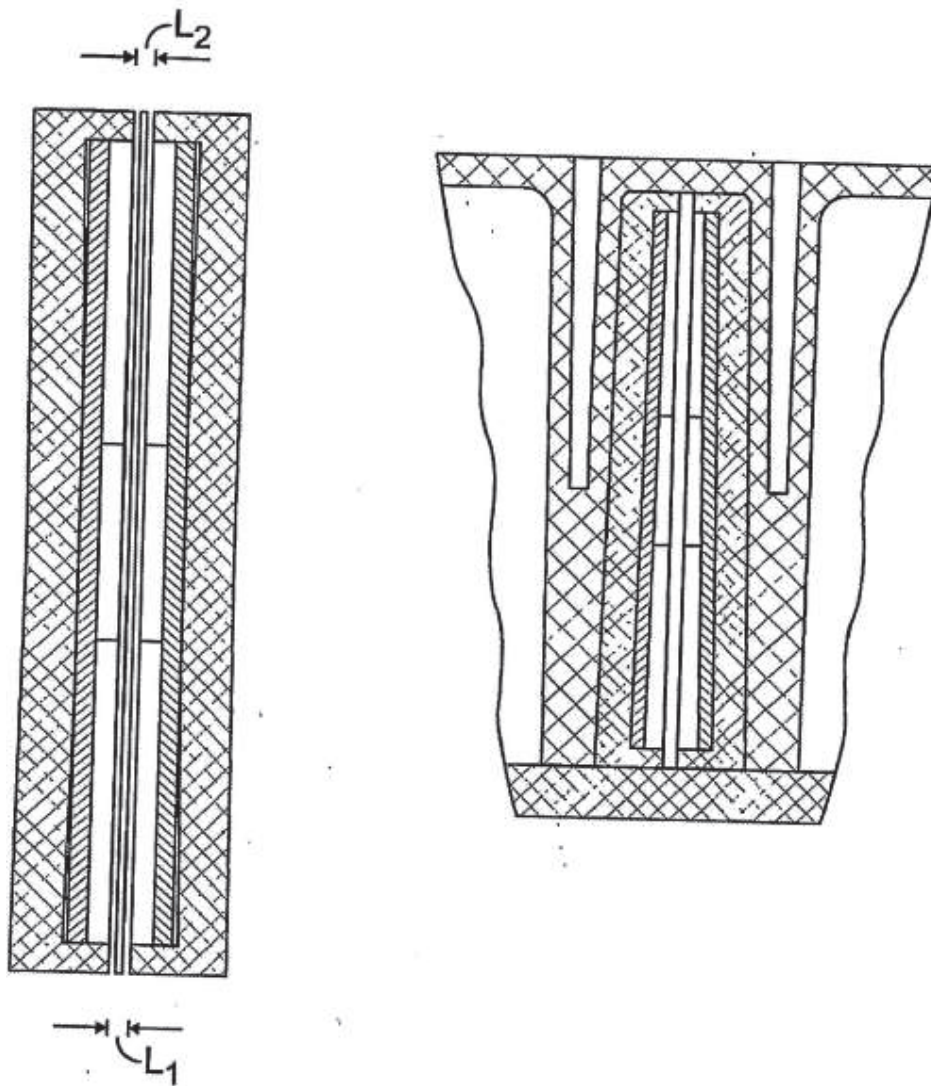


FIG. 6

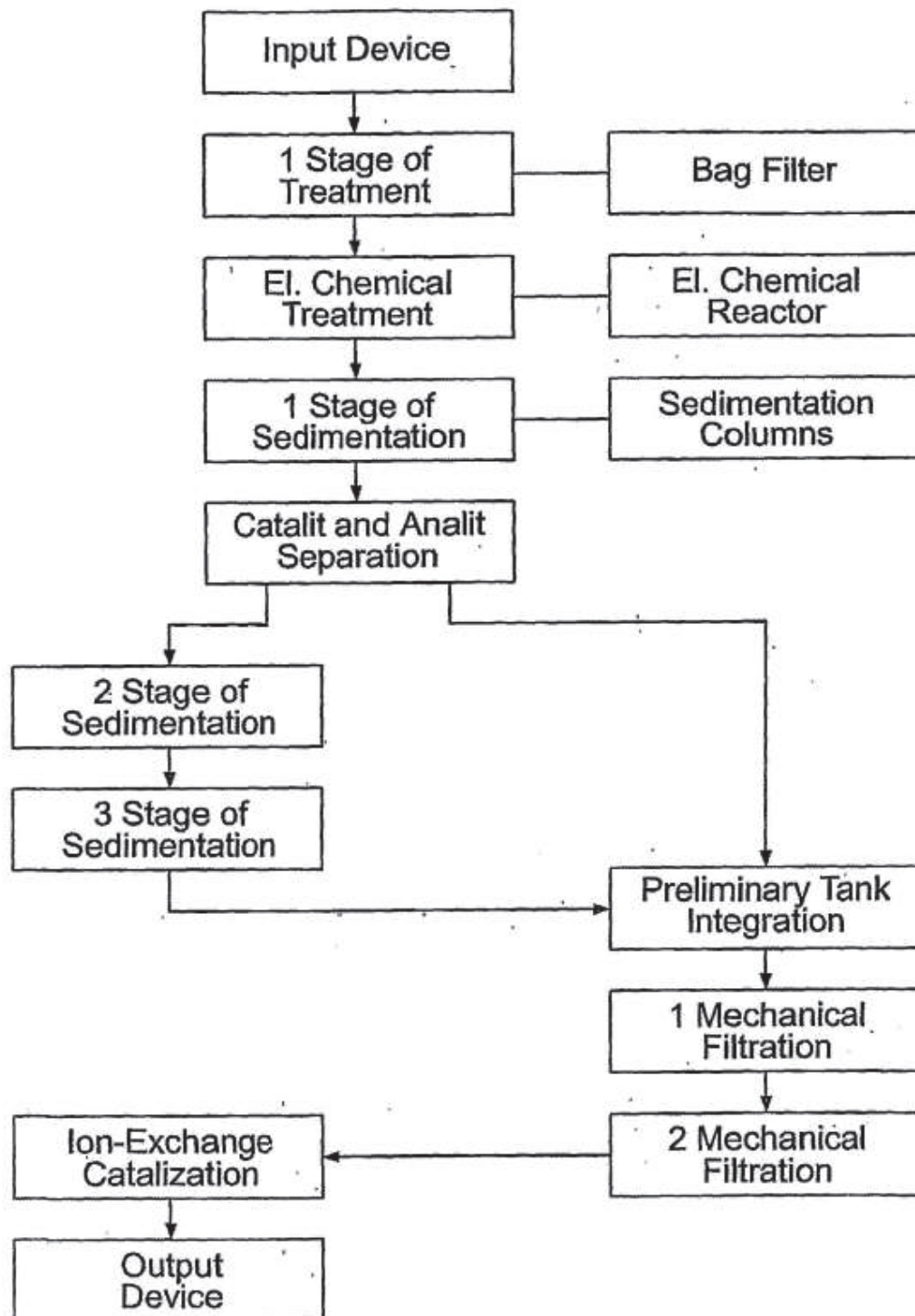


FIG. 7

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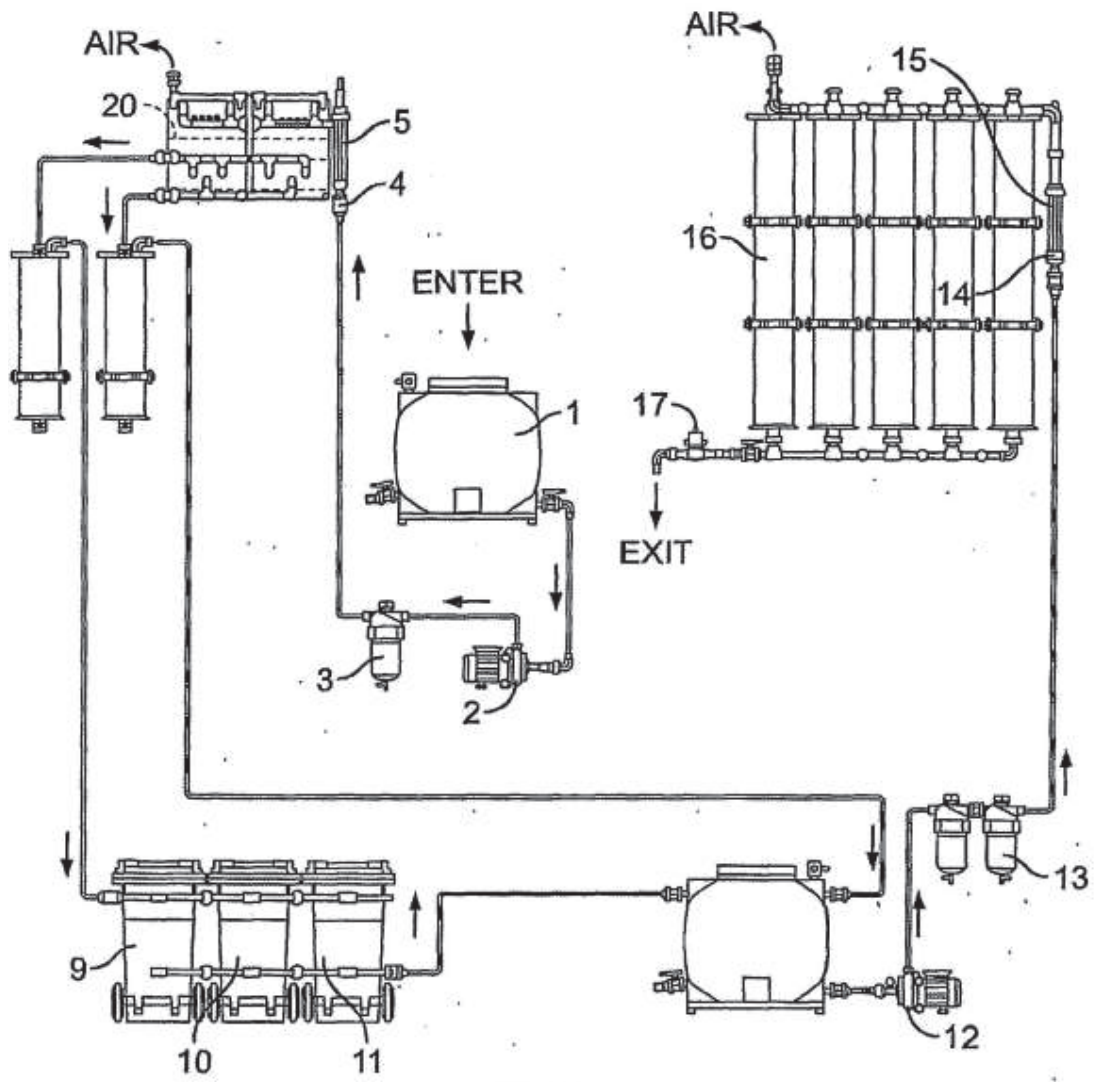


FIG. 8

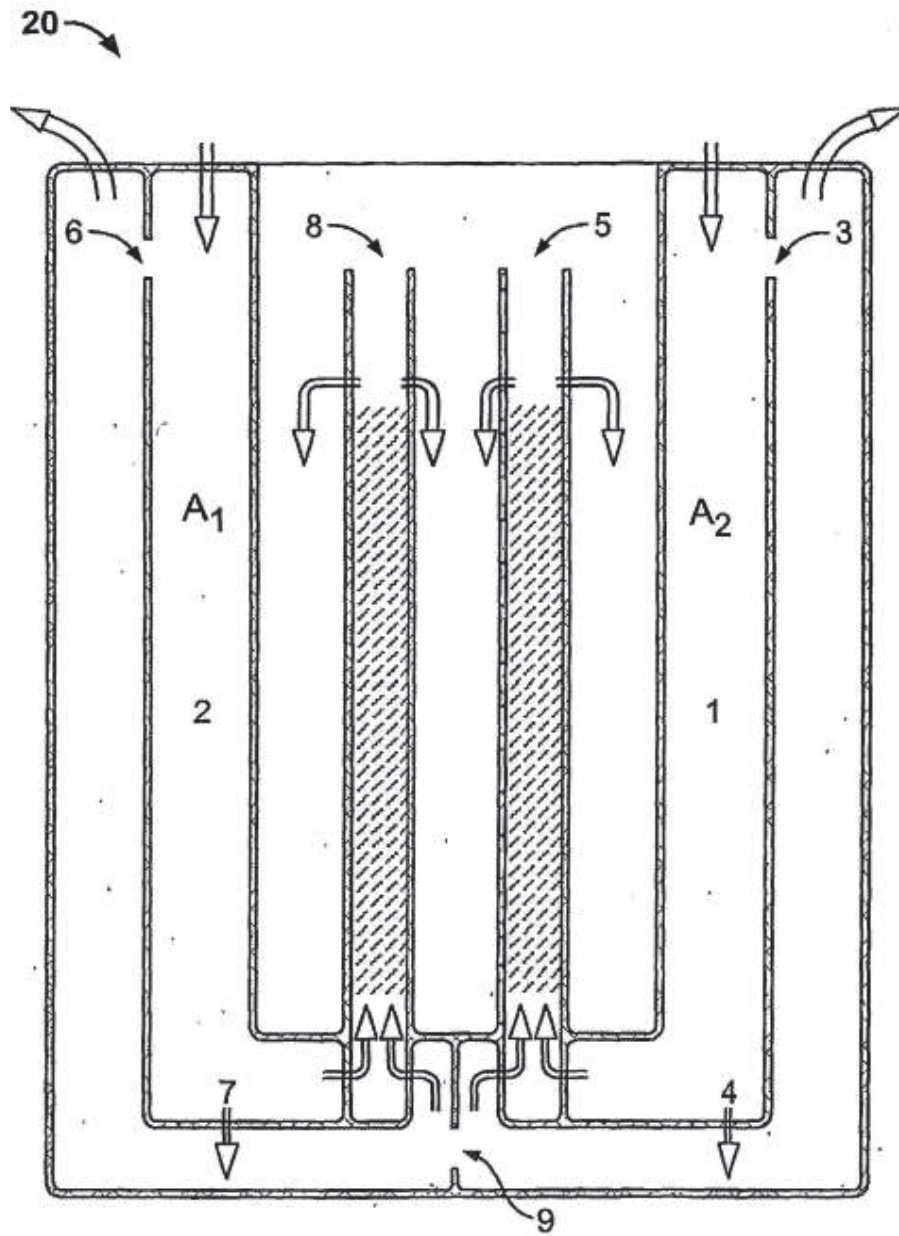


FIG. 9

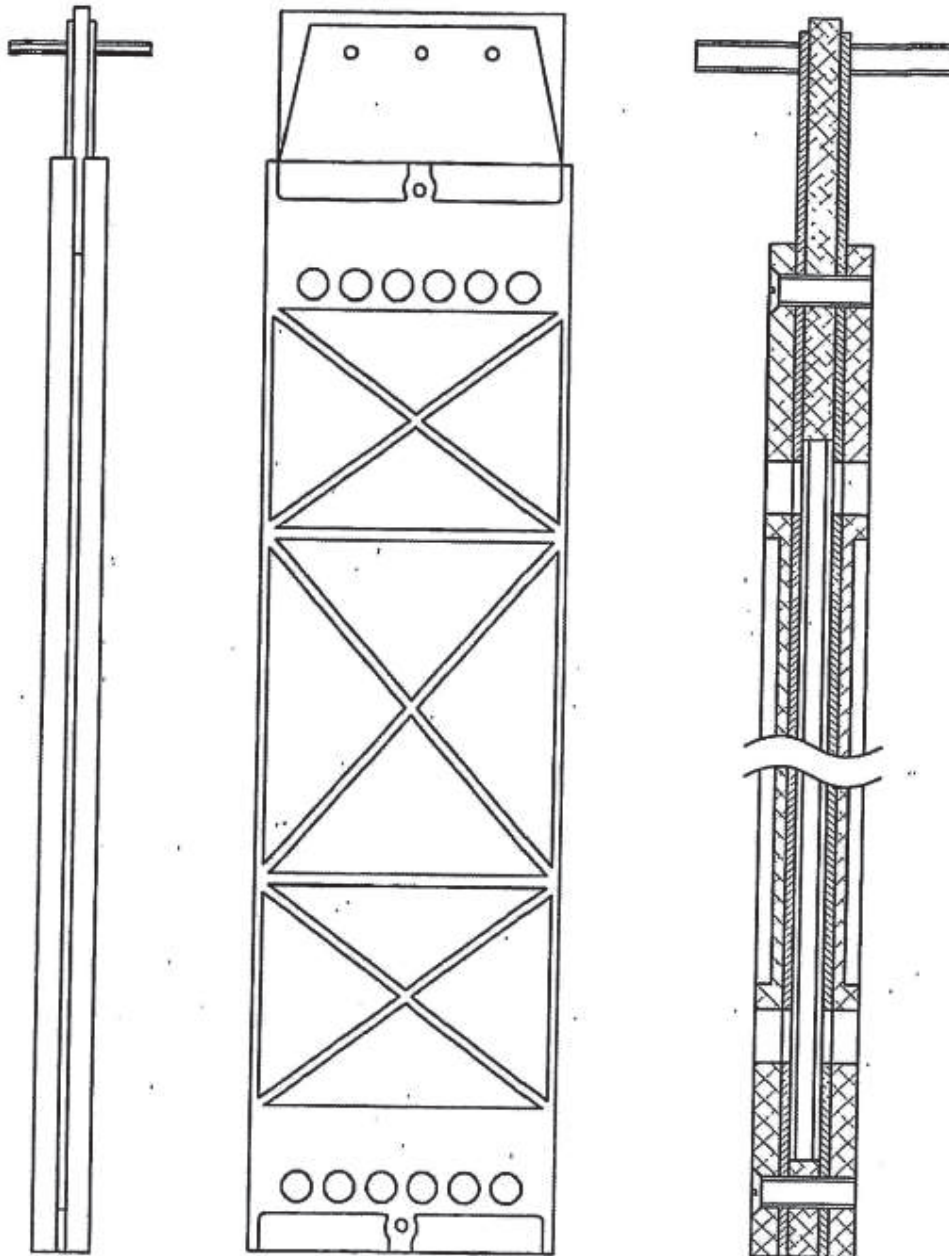


FIG. 10

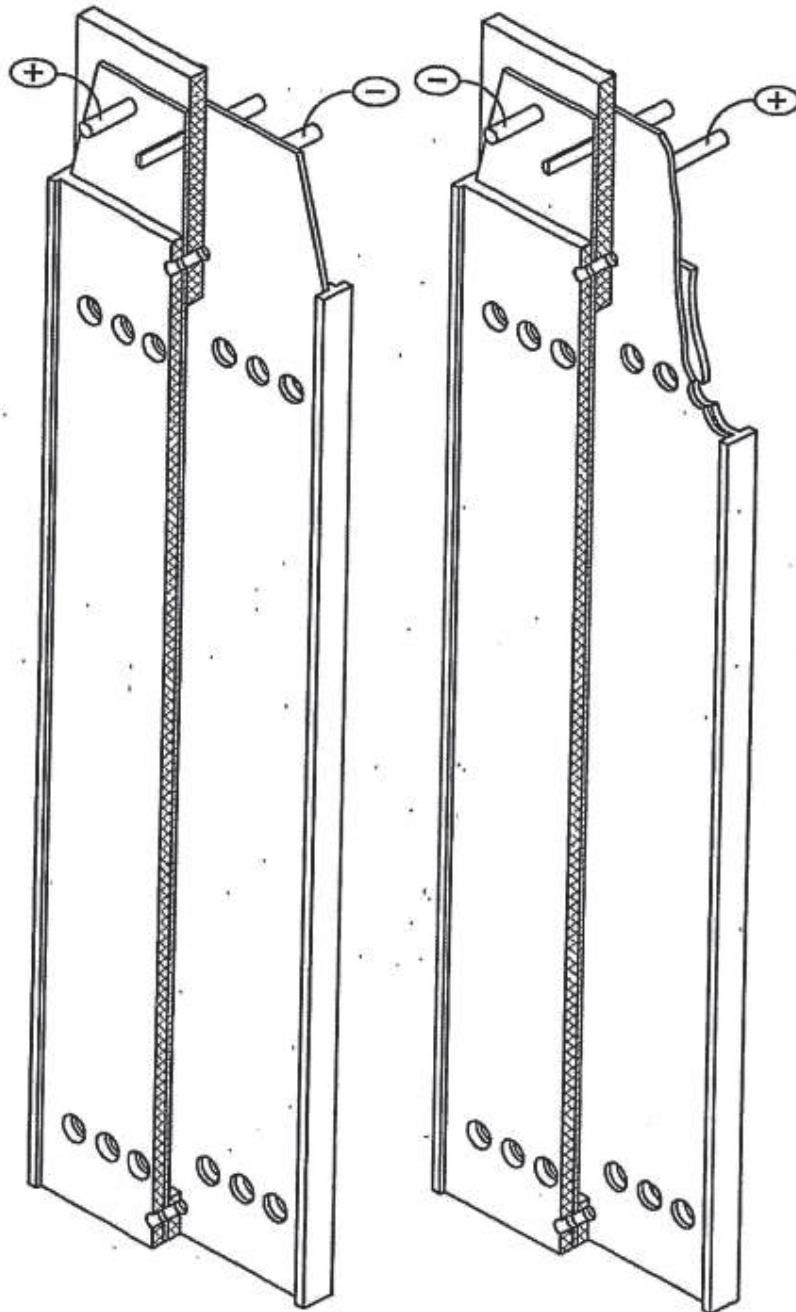


FIG. 11

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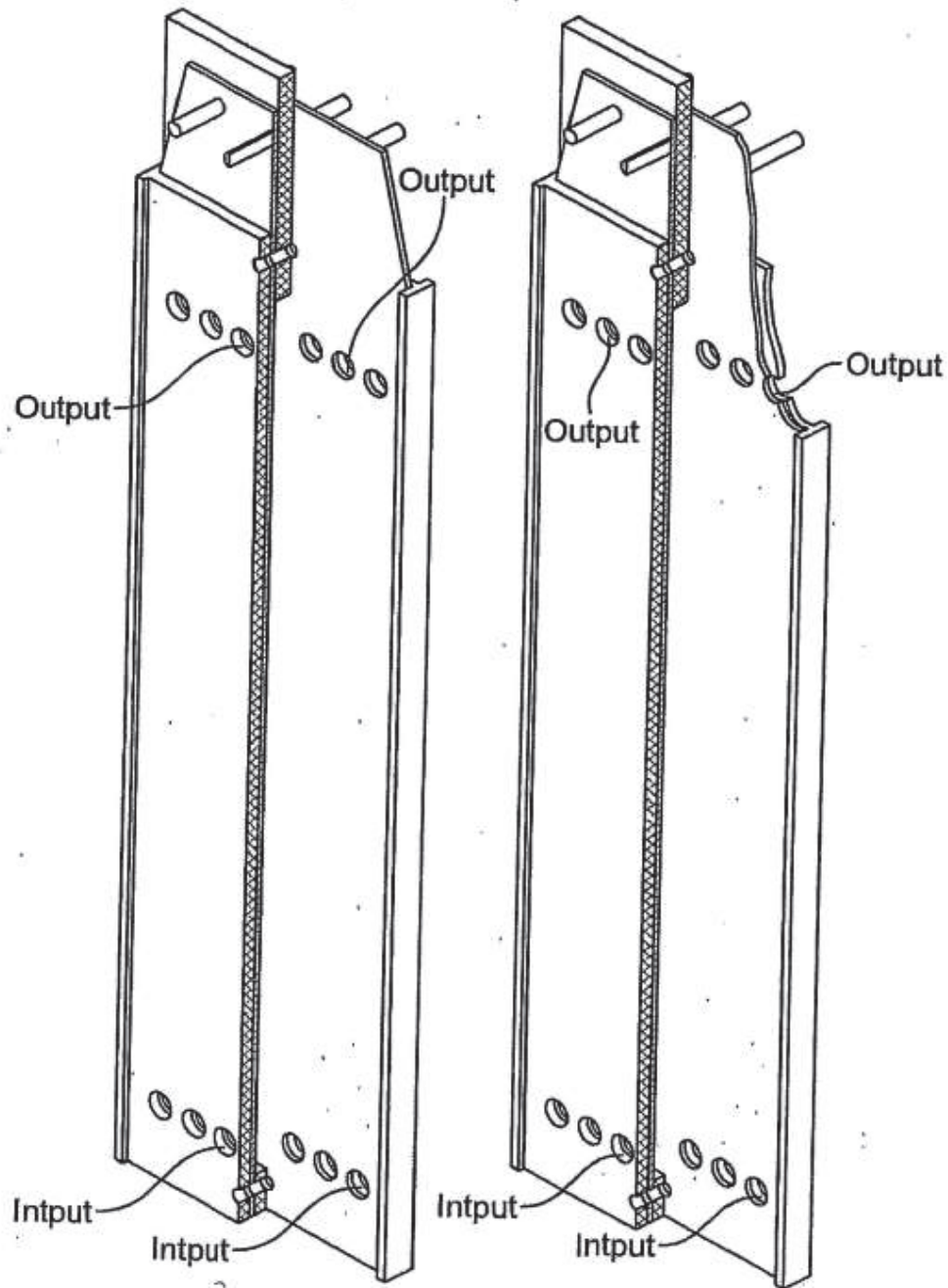


FIG. 12

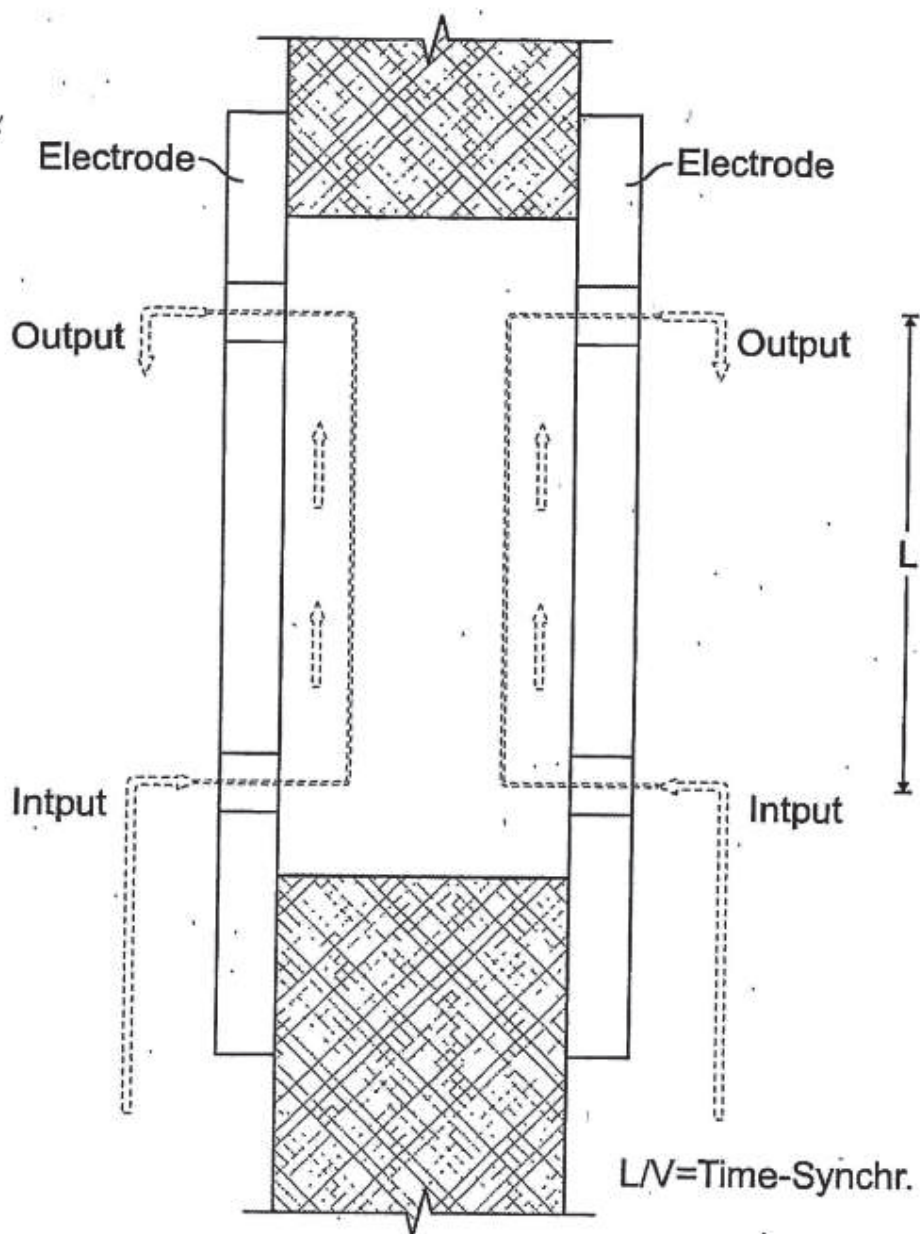


FIG. 13

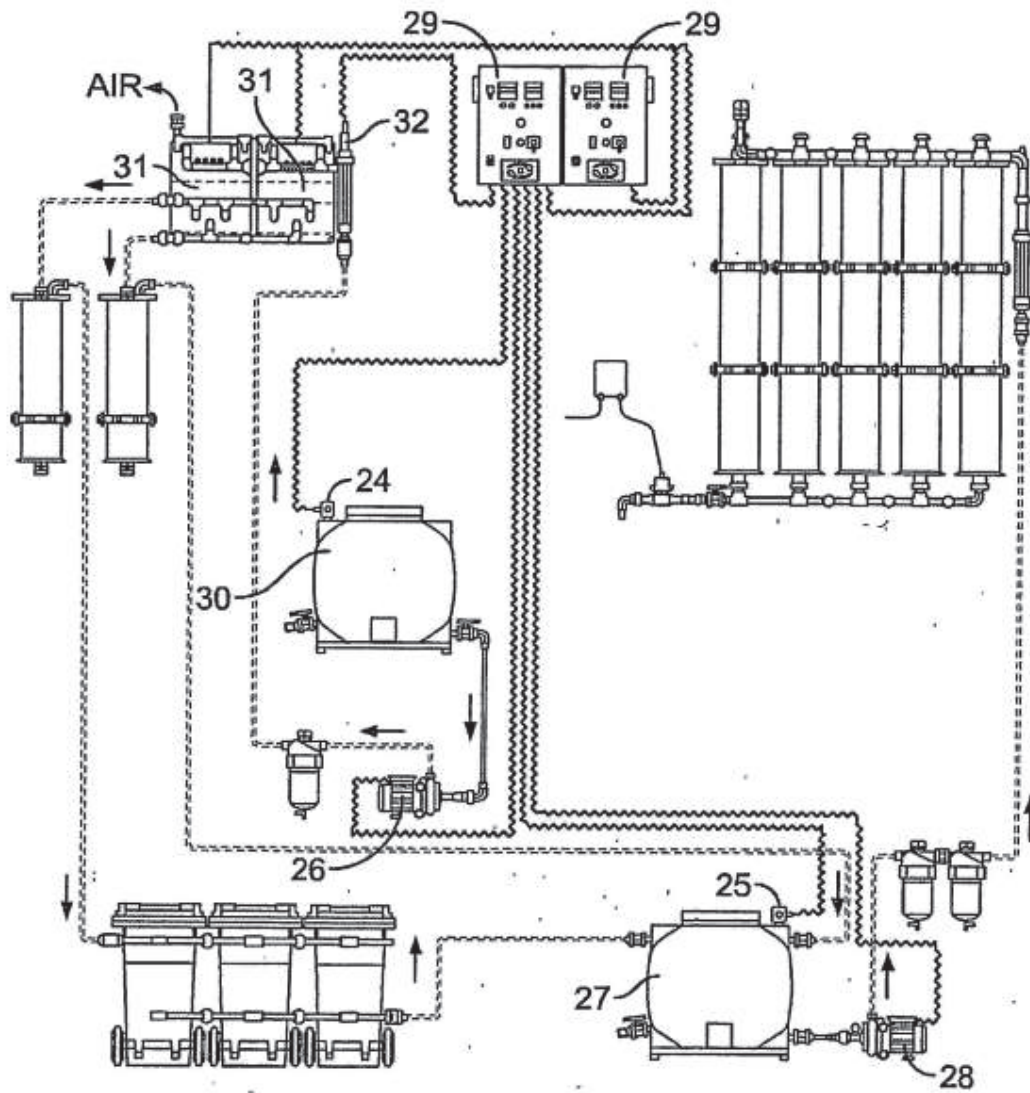


FIG. 14

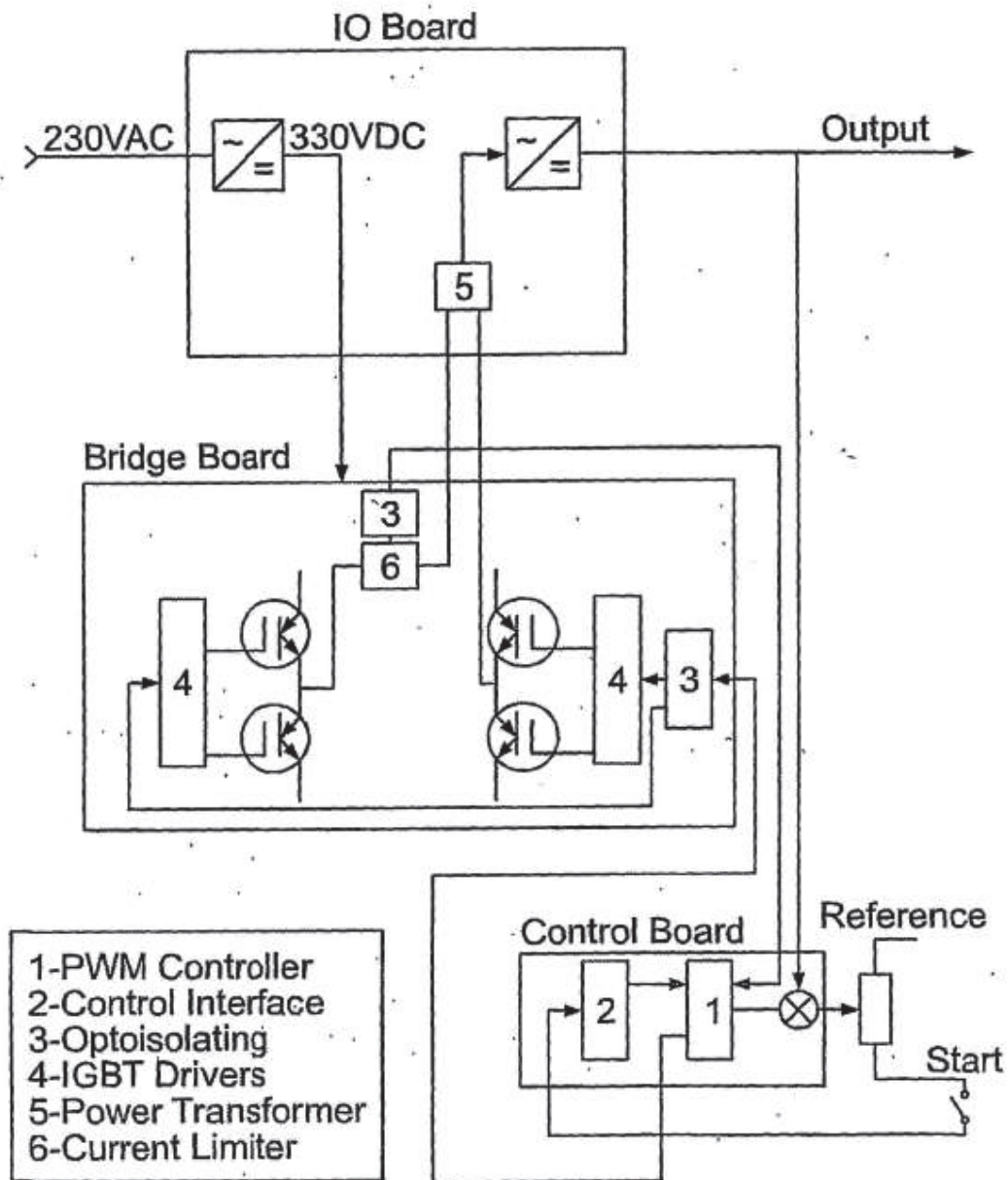


FIG. 15

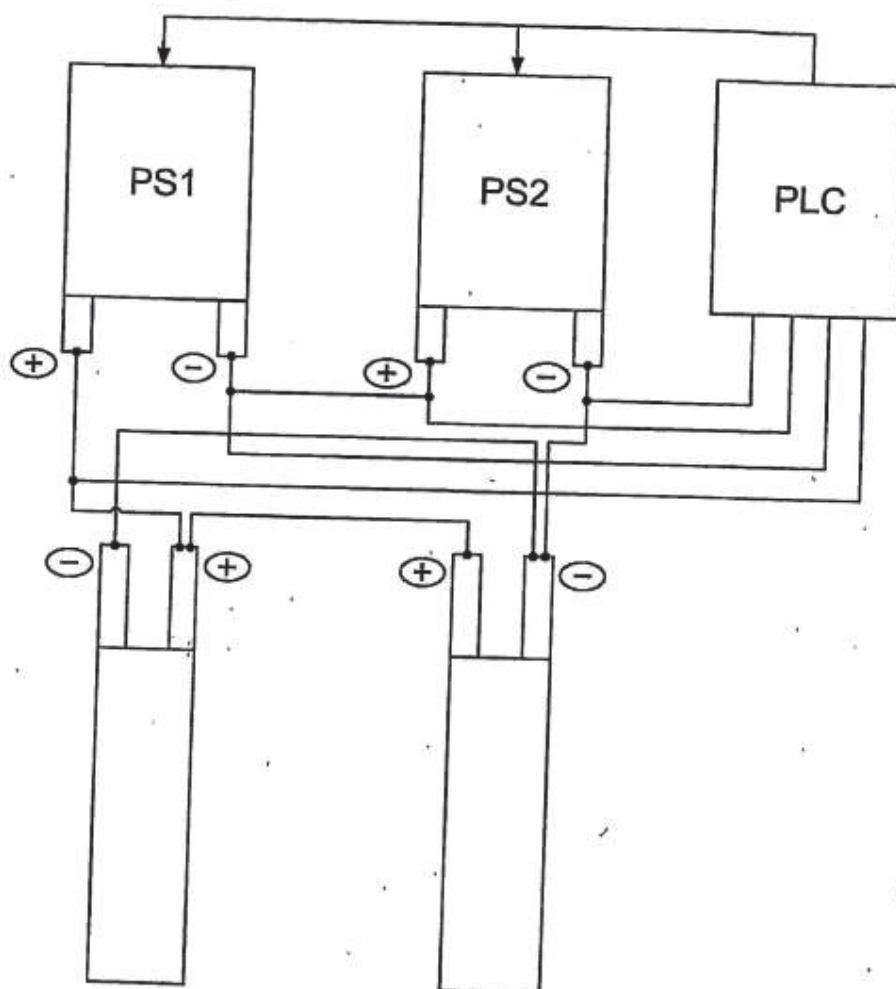


FIG. 16

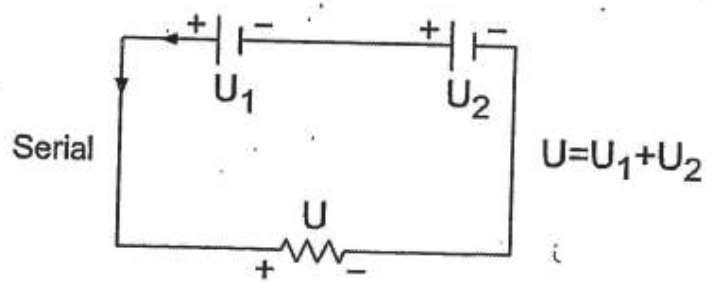
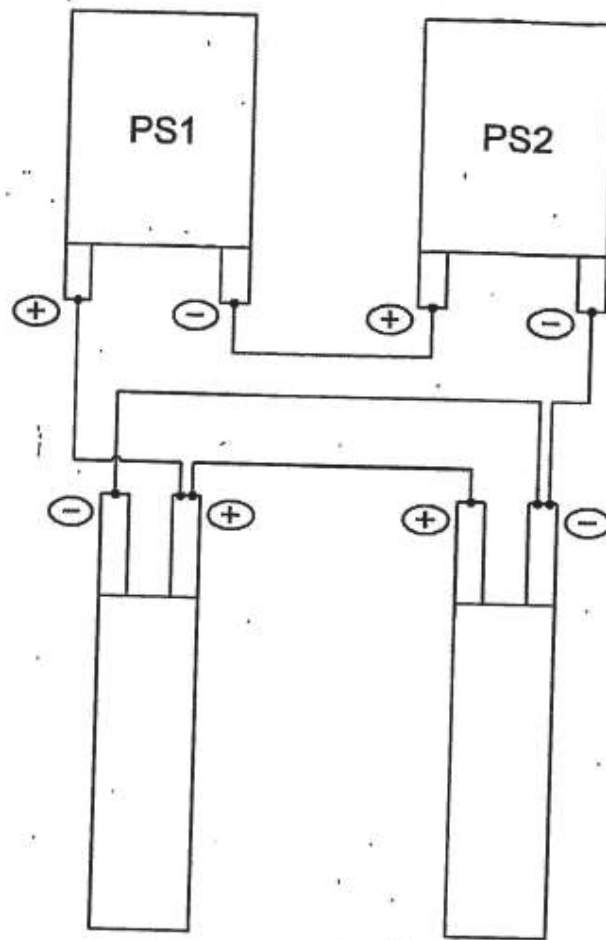


FIG. 17

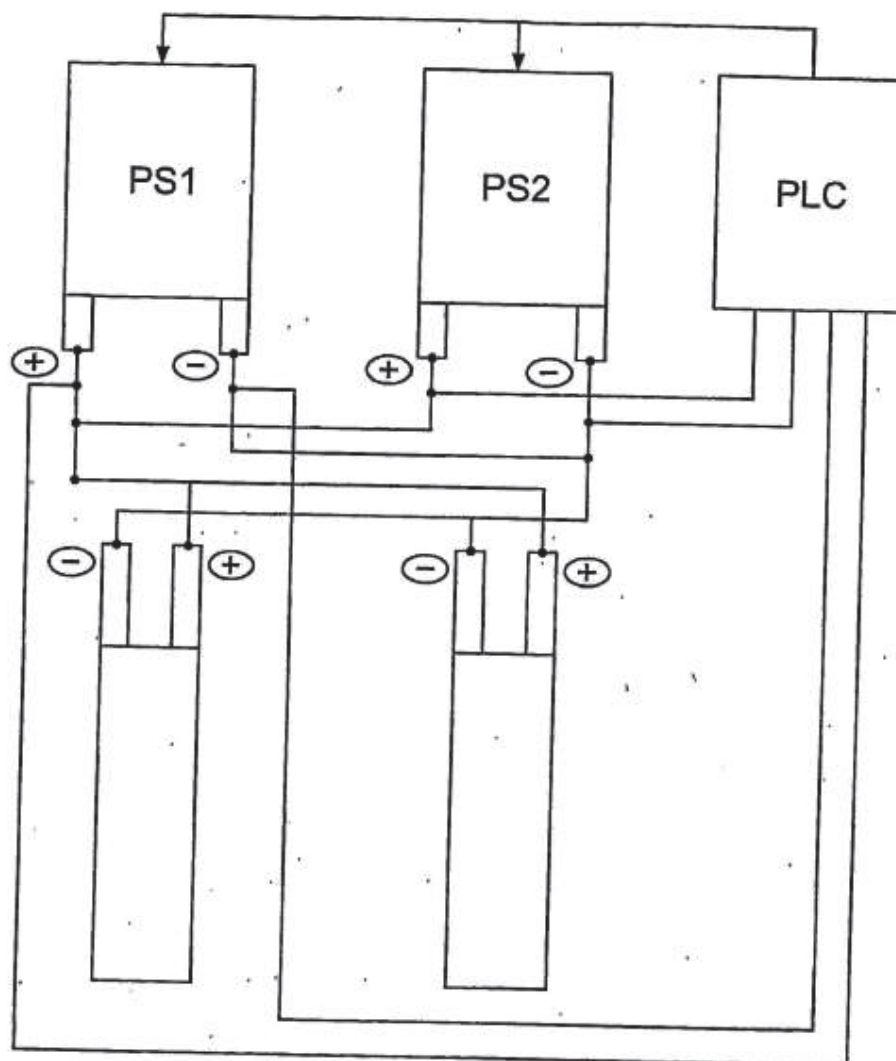


FIG. 18

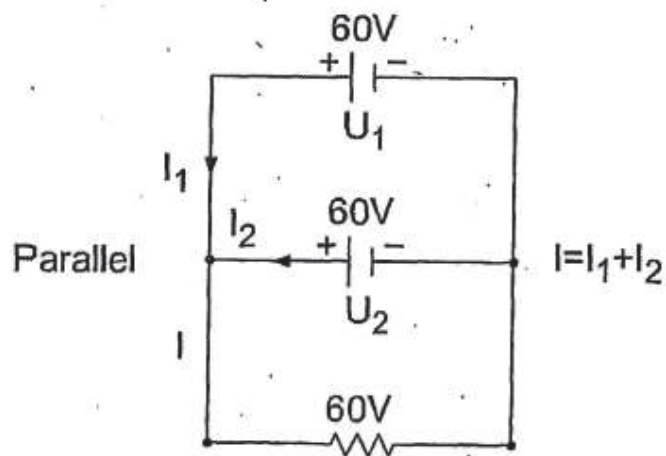
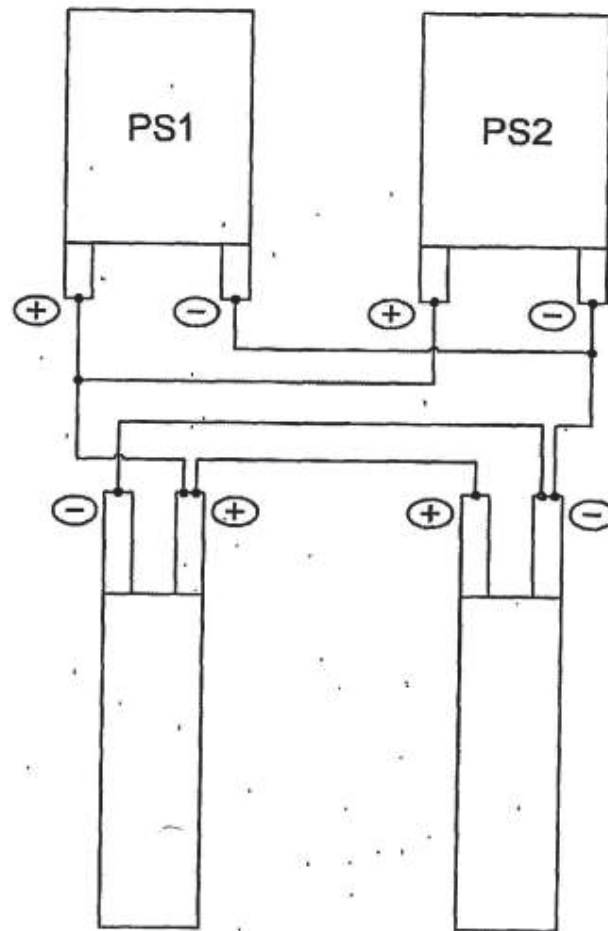


FIG. 19

SUBSTITUTE SHEET (RULE 26)

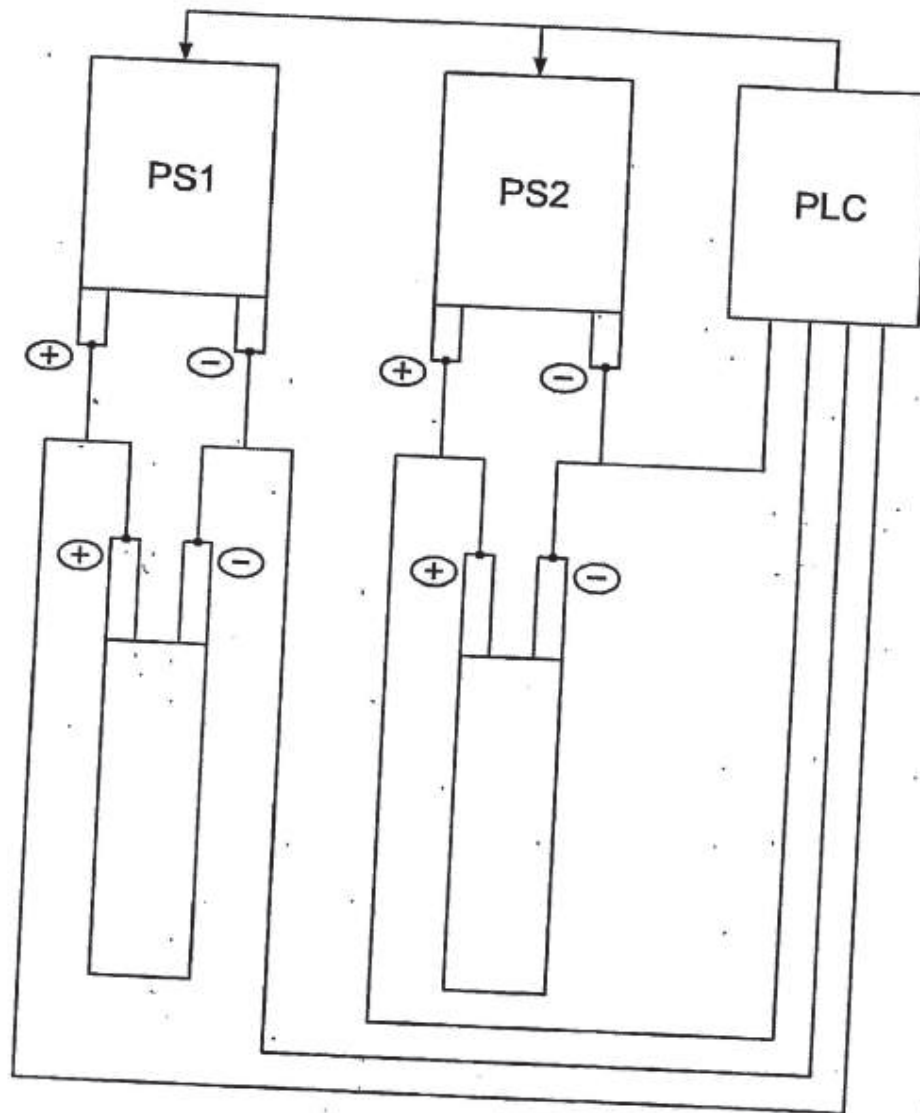


FIG. 20

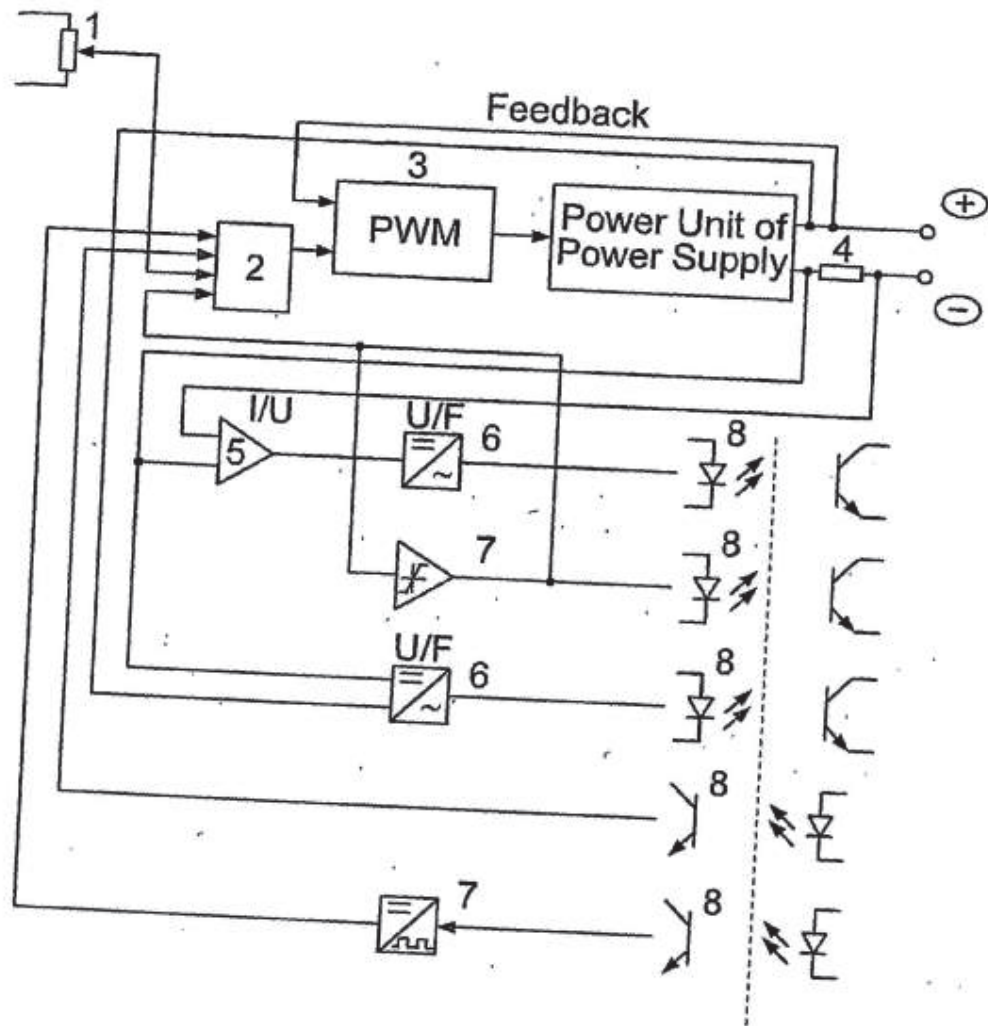


FIG. 21

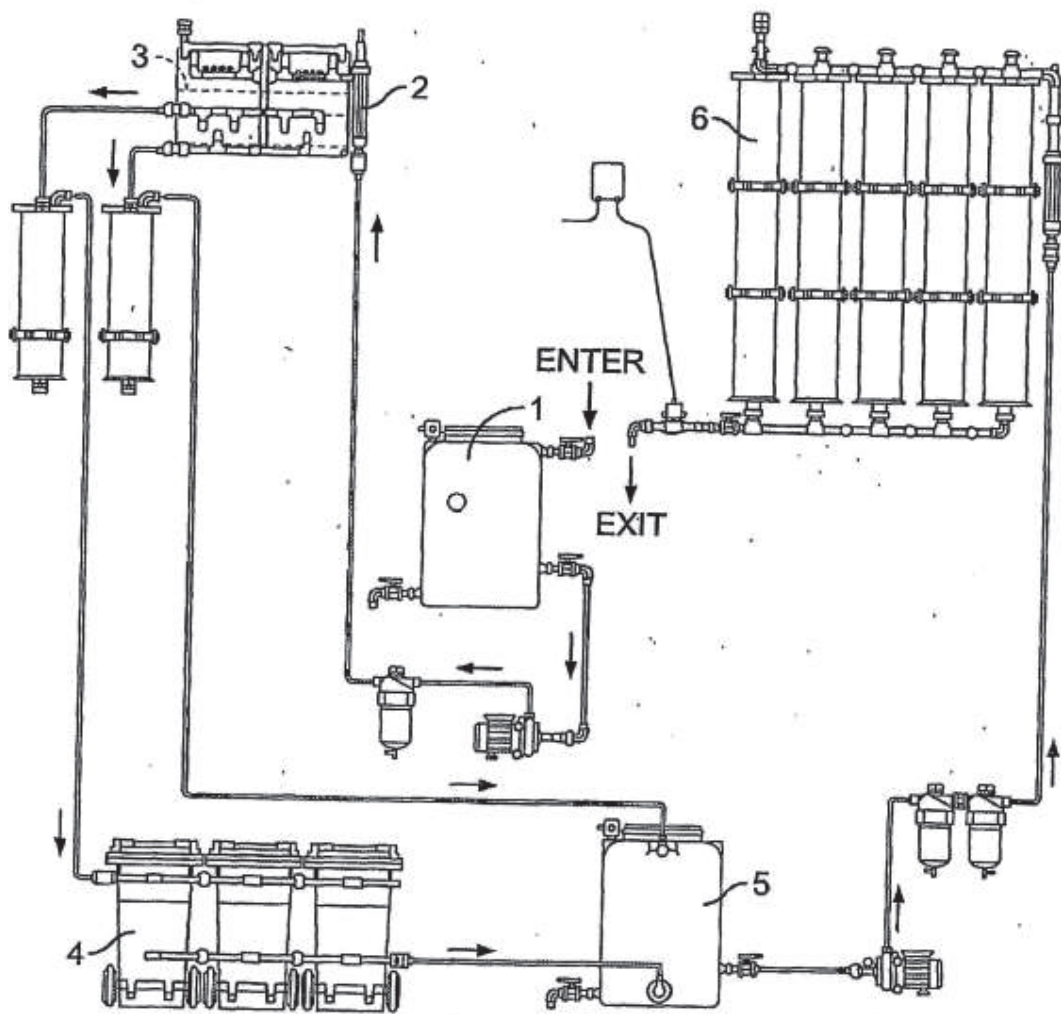


FIG. 22

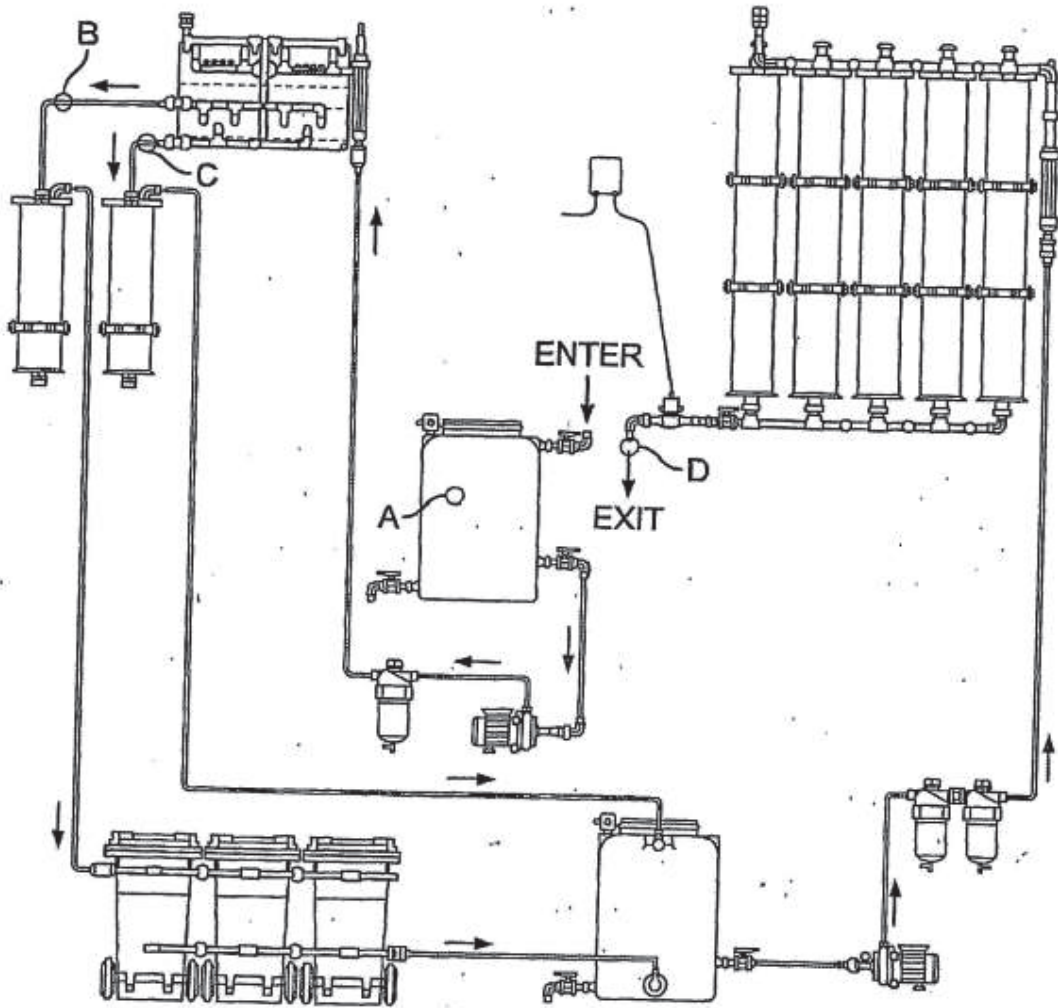


FIG. 23

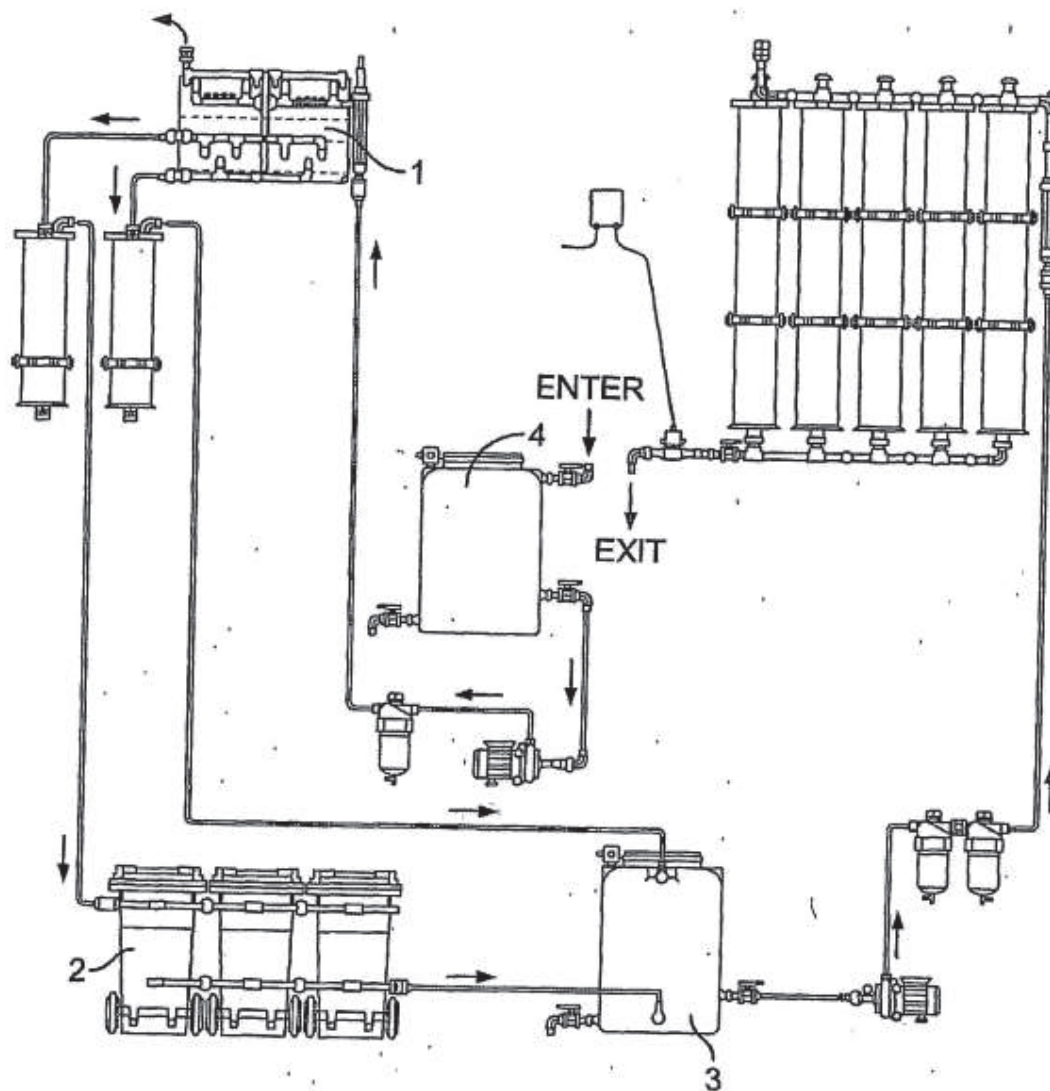


FIG. 24

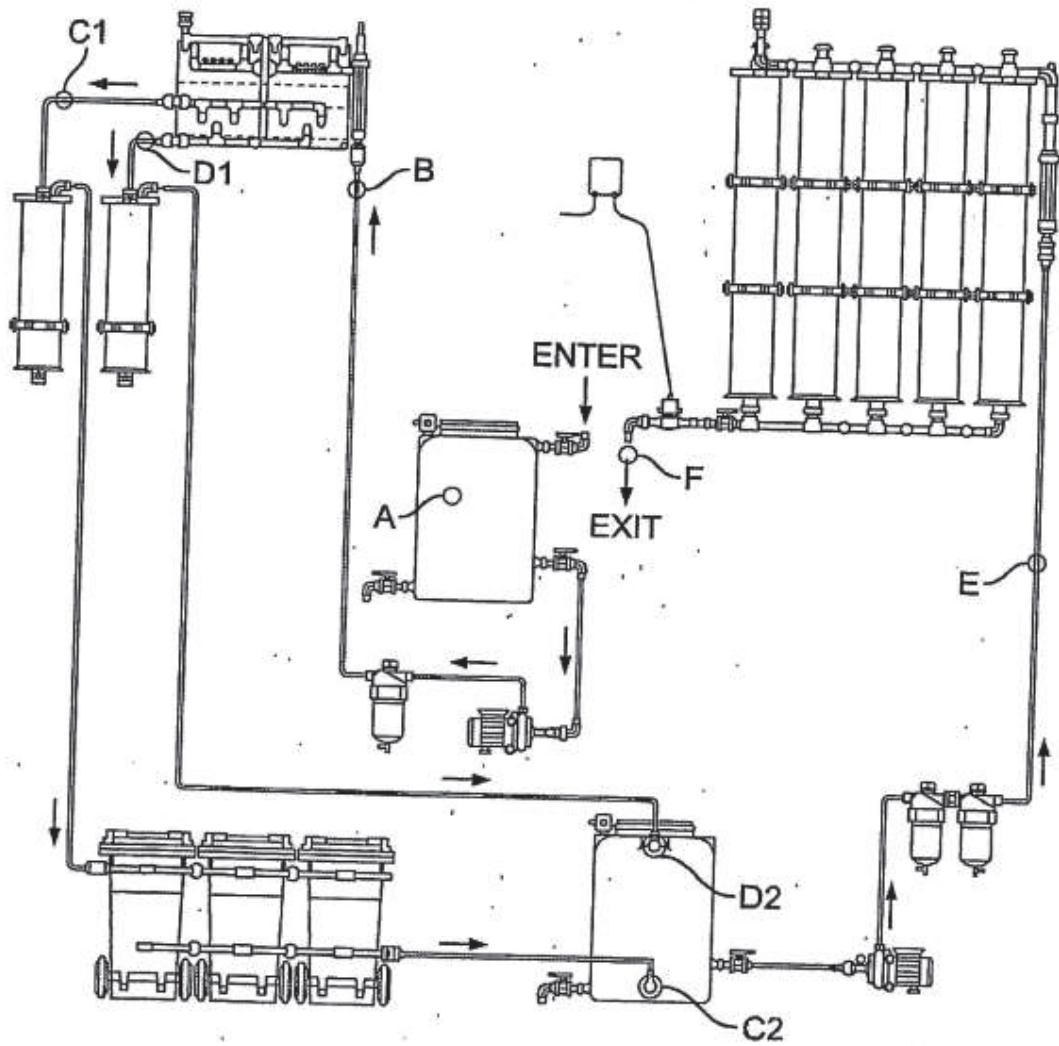


FIG. 25

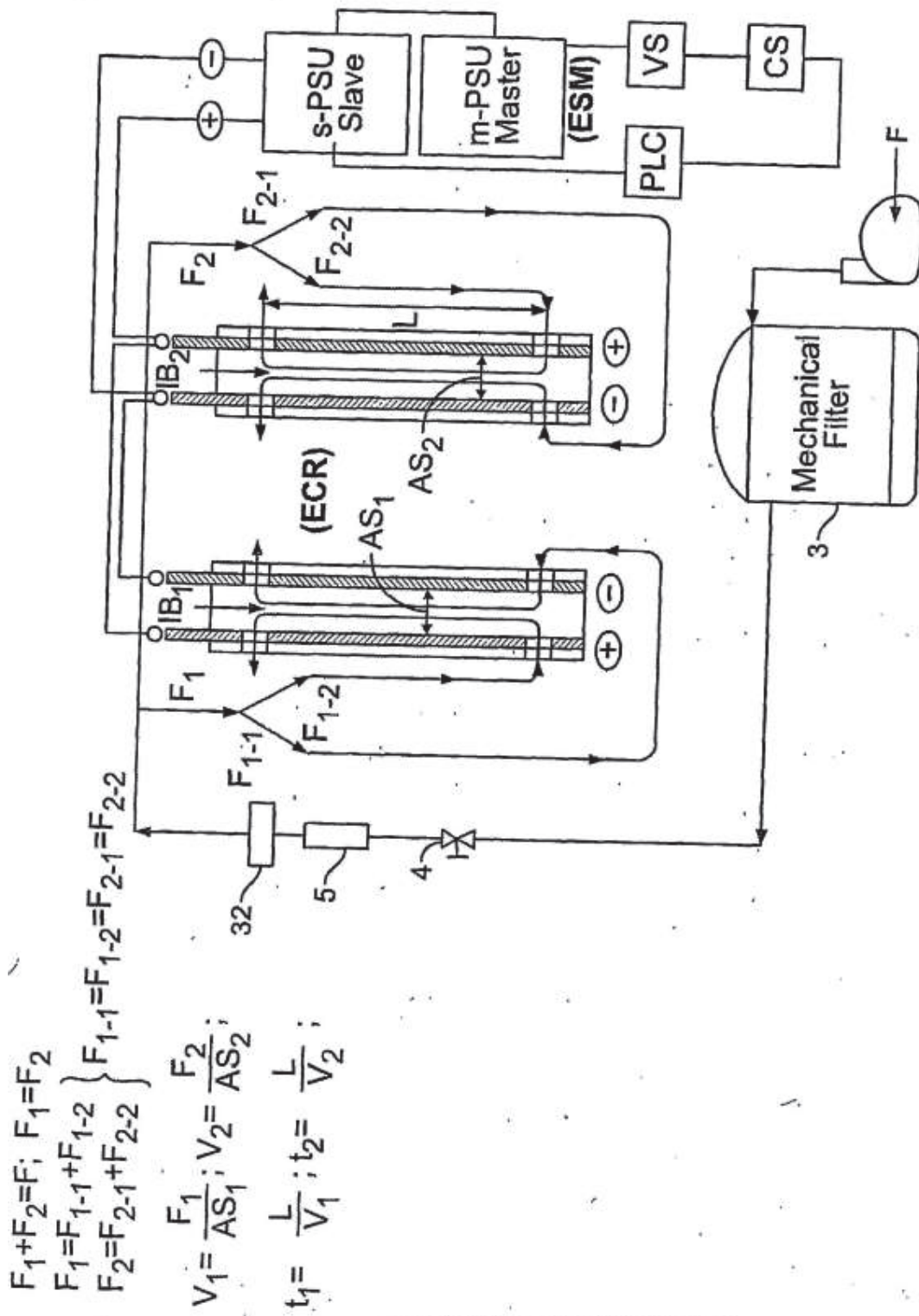


FIG. 26

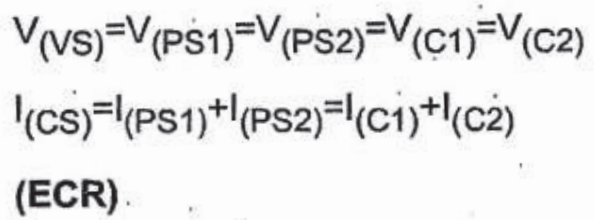


FIG. 27

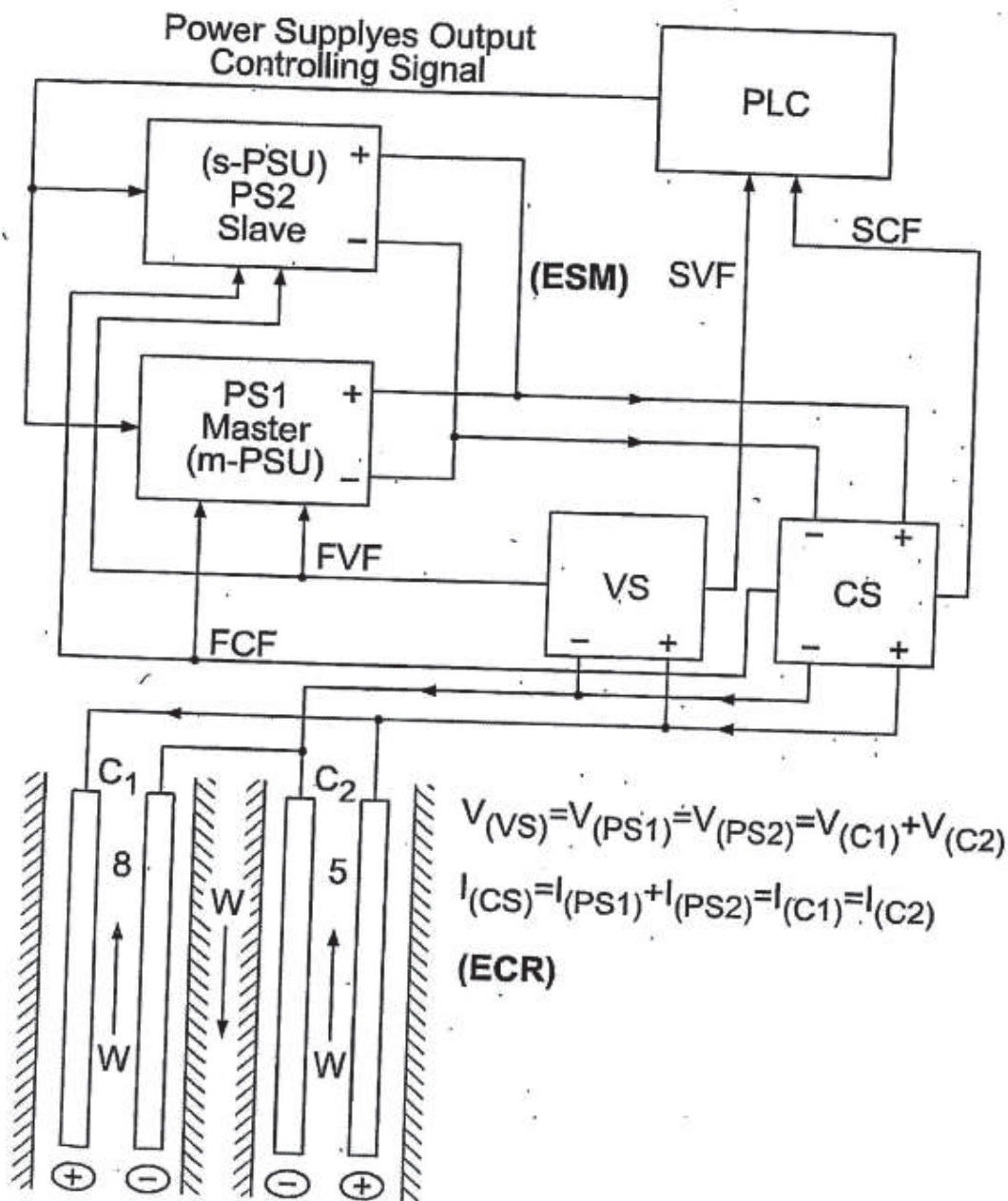


FIG. 28

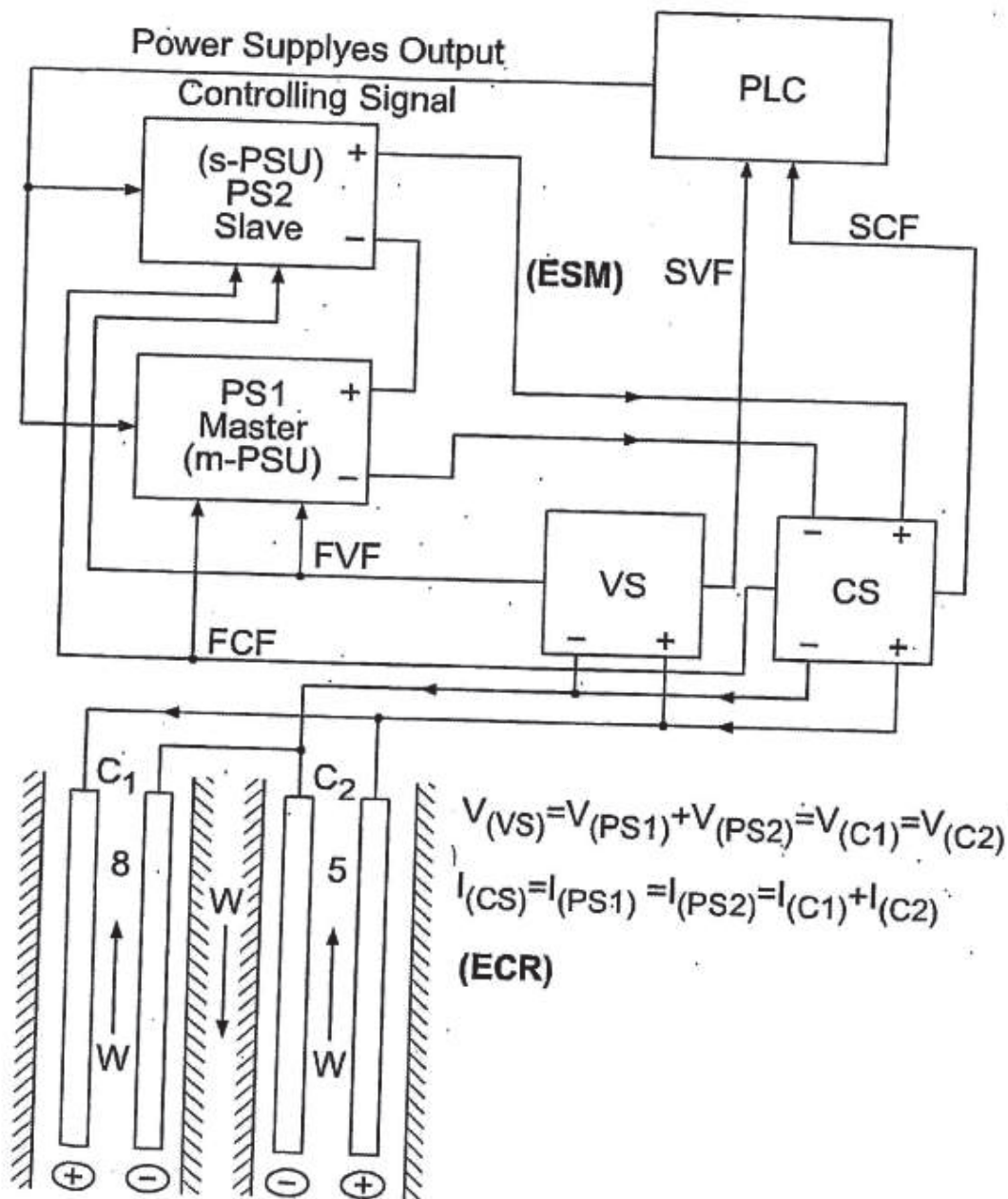


FIG. 29

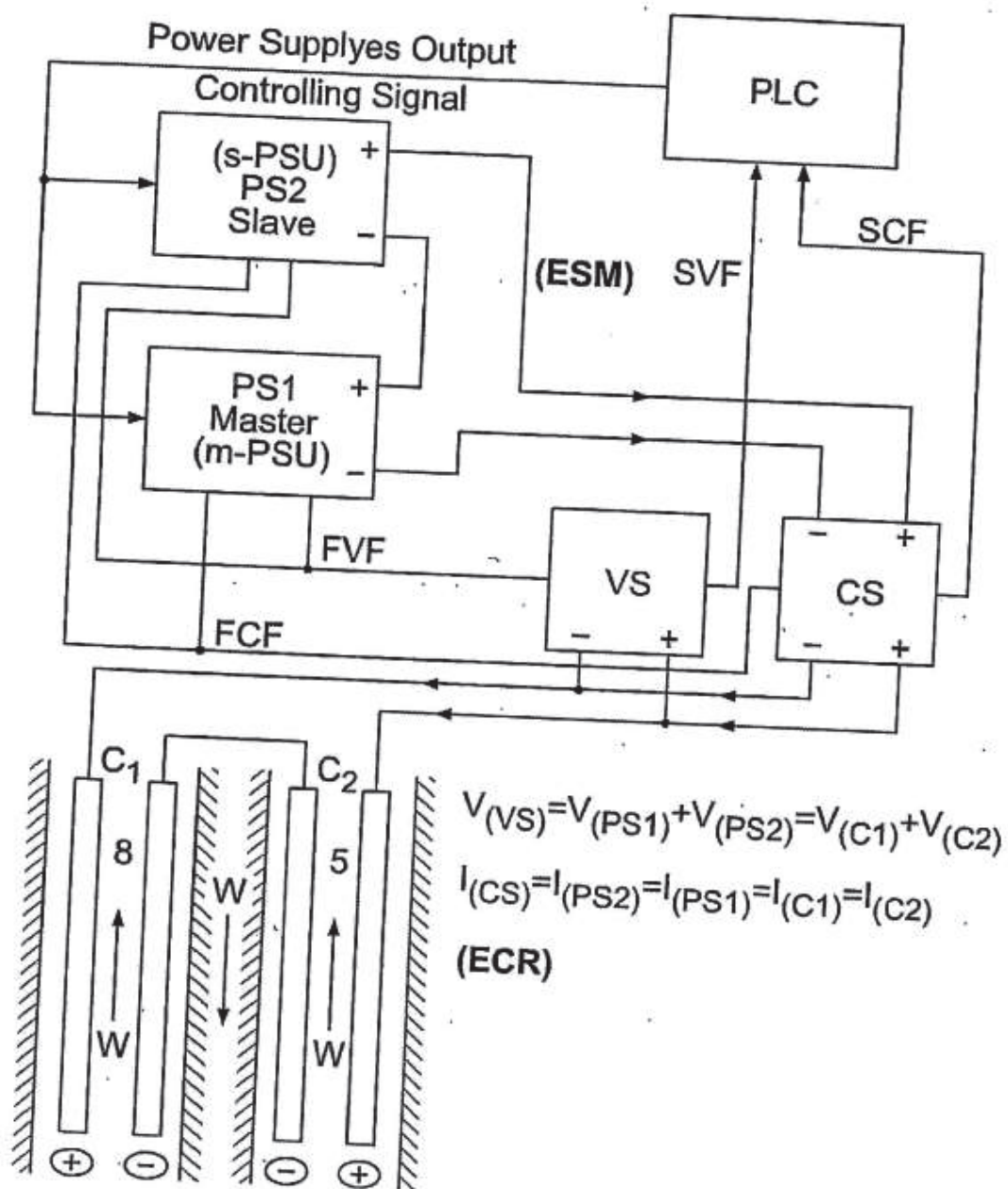


FIG. 30

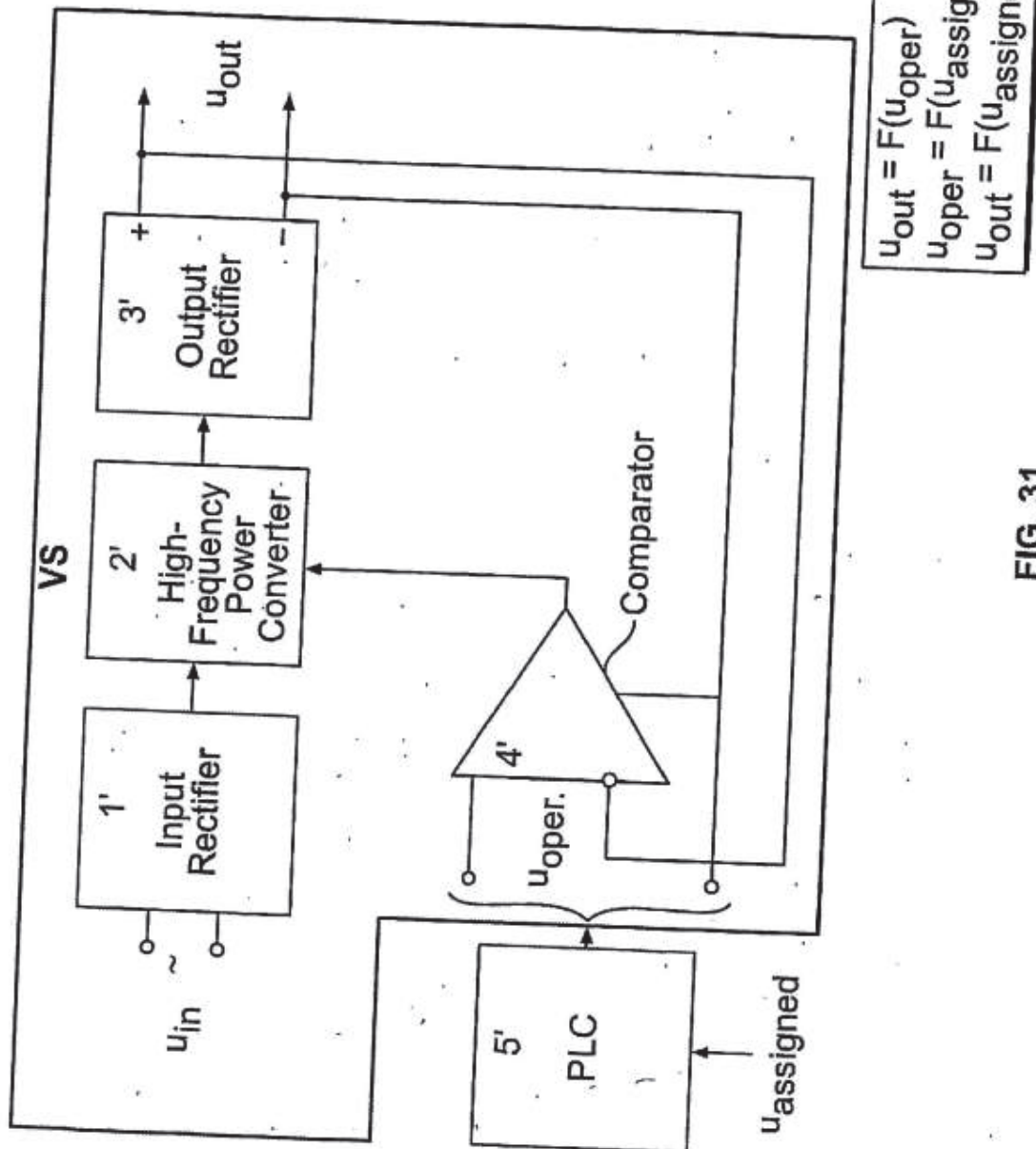


FIG. 31

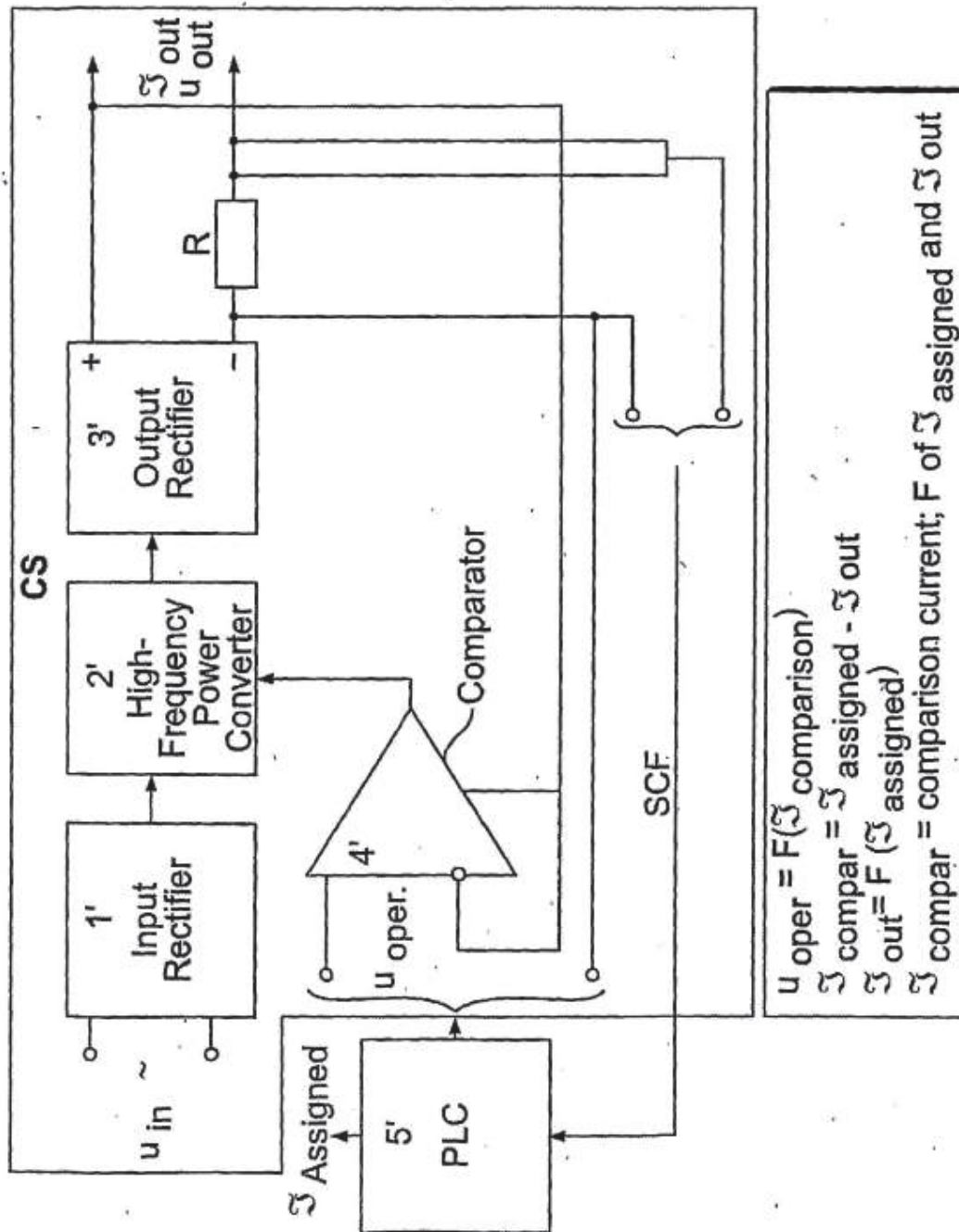


FIG. 32

Energy supply for waste water regeneration	2
Part 1—General Introduction and Overall Description	6
Part 2~Structure, Function, and Operation	12
Part 3~Exemplary “Actual” Practice and Applications, and Analysis of Results Obtained Therefrom	35
Part 4. Detailed Description of How the Power Control of the Present Invention 10 Synchronizes the Power Supply to a W2W Electrochemical Reactor	46
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