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(54) **ELECTROCHEMICAL LIQUID TREATMENT SYSTEM USING DOSE CONTROL**

(76) Inventors: **James A. Tretheway**, Madison, WI (US); **Brian R. Hale**, Lake Mills, WI (US); **Dennis E. Bahr**, Madison, WI (US); **Ajit K. Chowdhury**, Madison, WI (US); **Jeremy J. Vogel**, Fort Atkinson, WI (US); **Karl W. Marschke**, Madison, WI (US)

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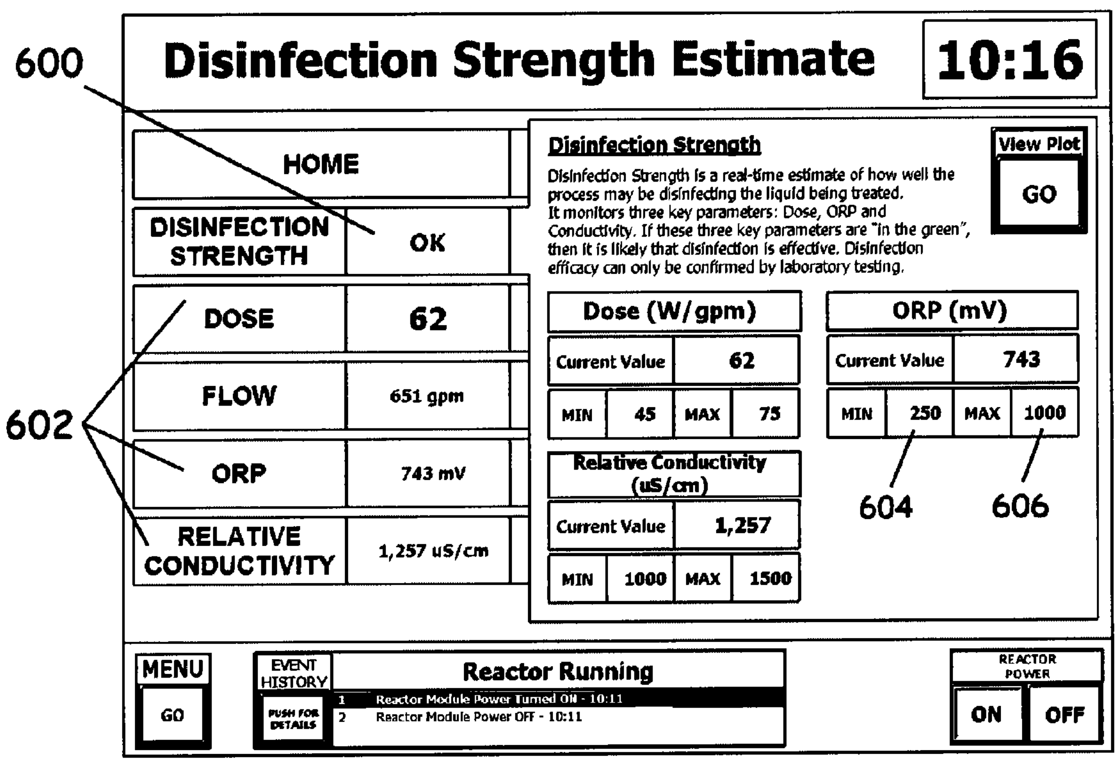
(57) **ABSTRACT**

The invention herein provides an apparatus and method of controlling an electrochemical treatment process where treatment is performed in a flow cell to ensure that a controlled dose of electrical energy or current is delivered to all volumes of the liquid being treated. In addition the invention provides for further optimization of the dose based on other factors and sensor inputs. This invention also provides a method to estimate, display and record a forecast of process efficacy such as disinfection, oxidation or other desired treatment that otherwise cannot be measured in an online manner.



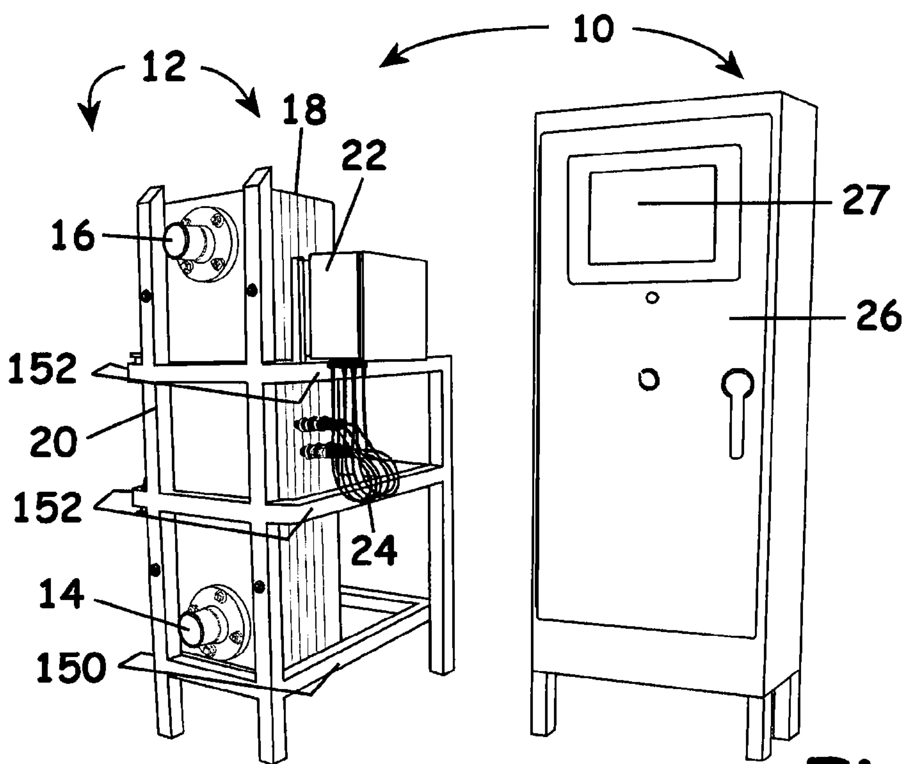
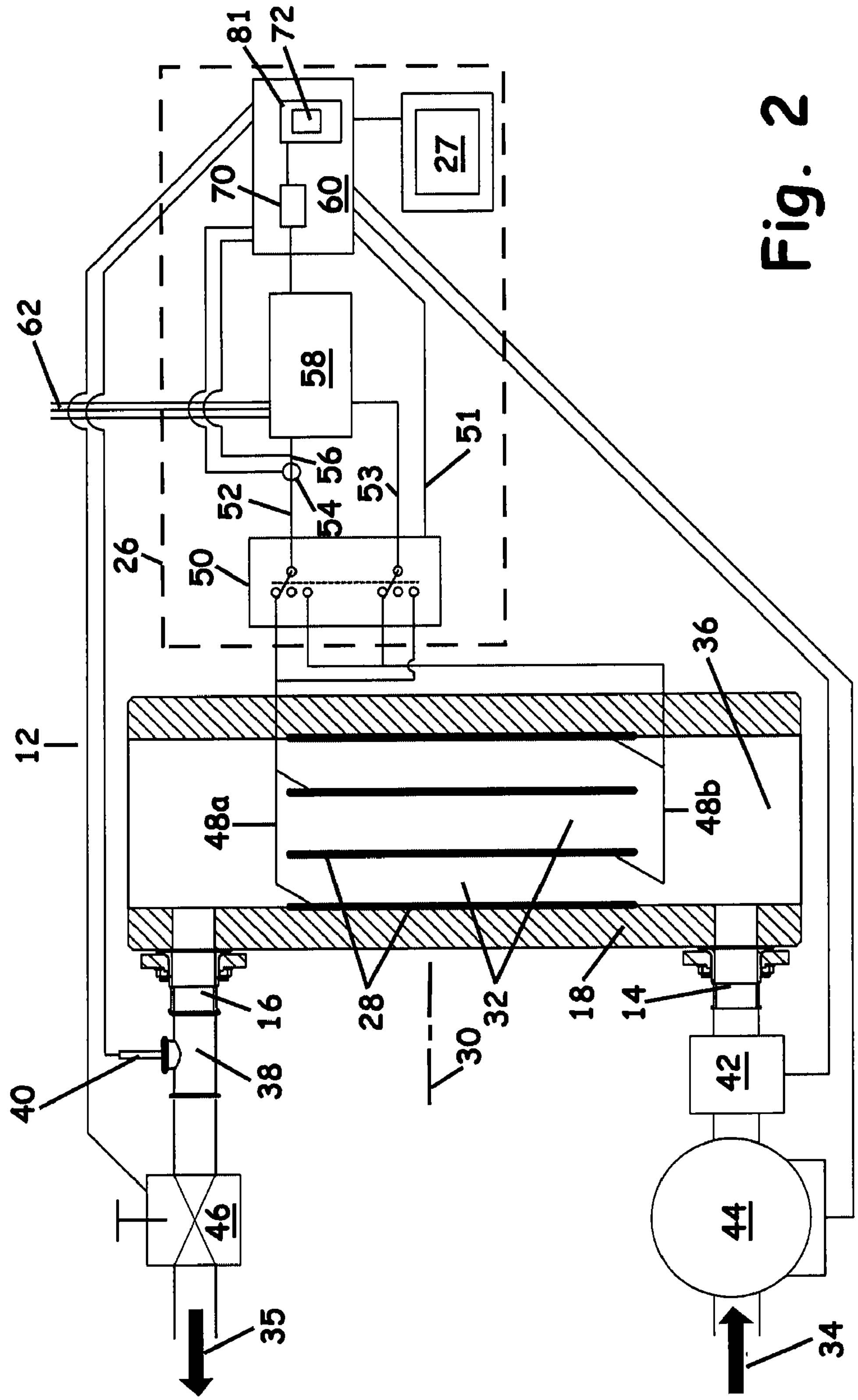


Fig. 1


81
72
70
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34

Fig. 2

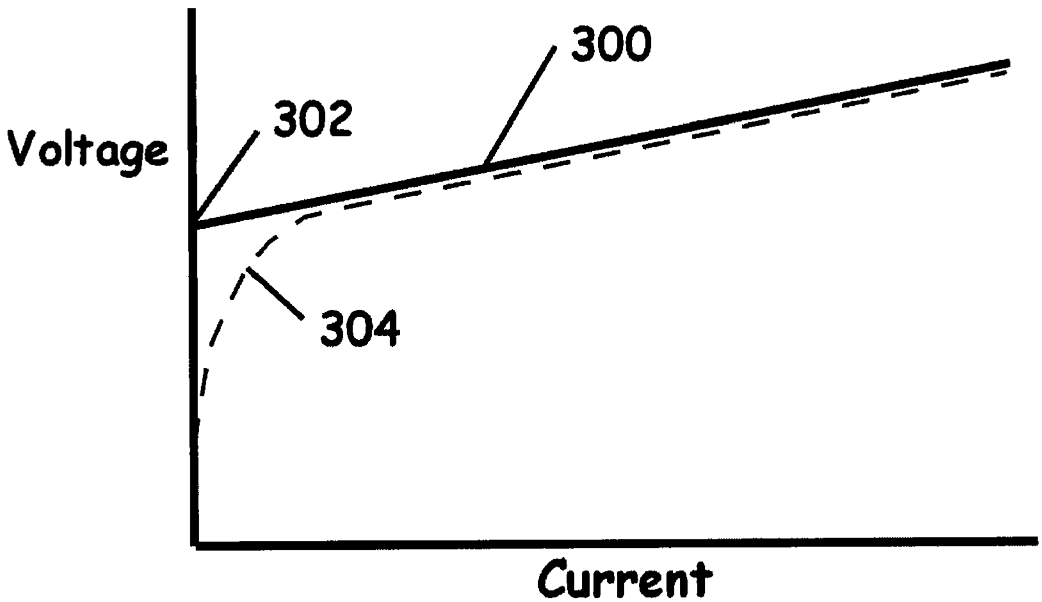

Fig. 3

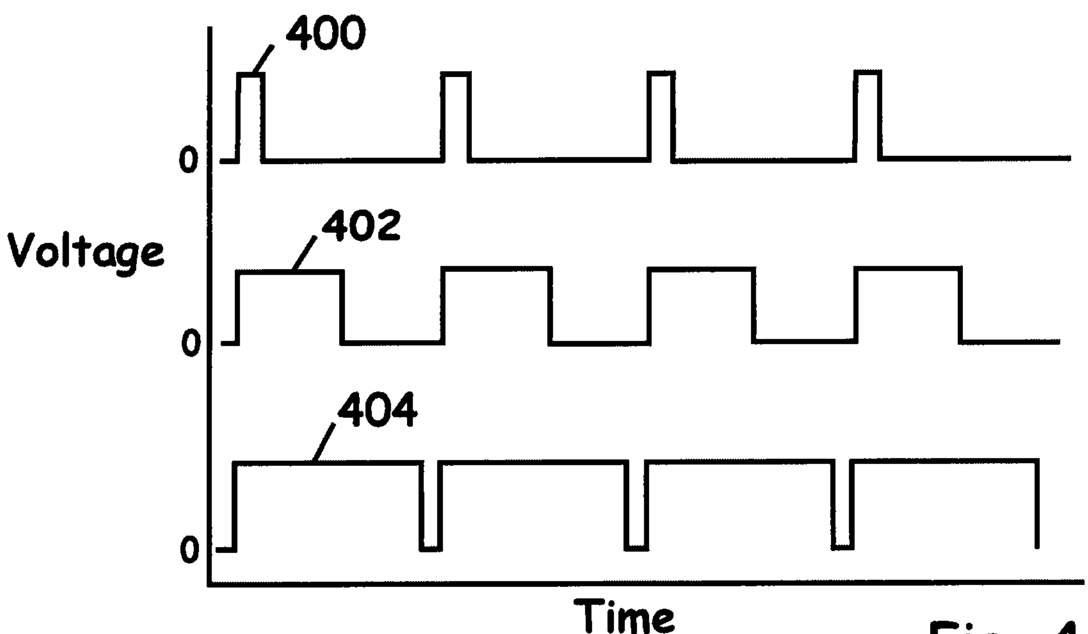

Fig. 4

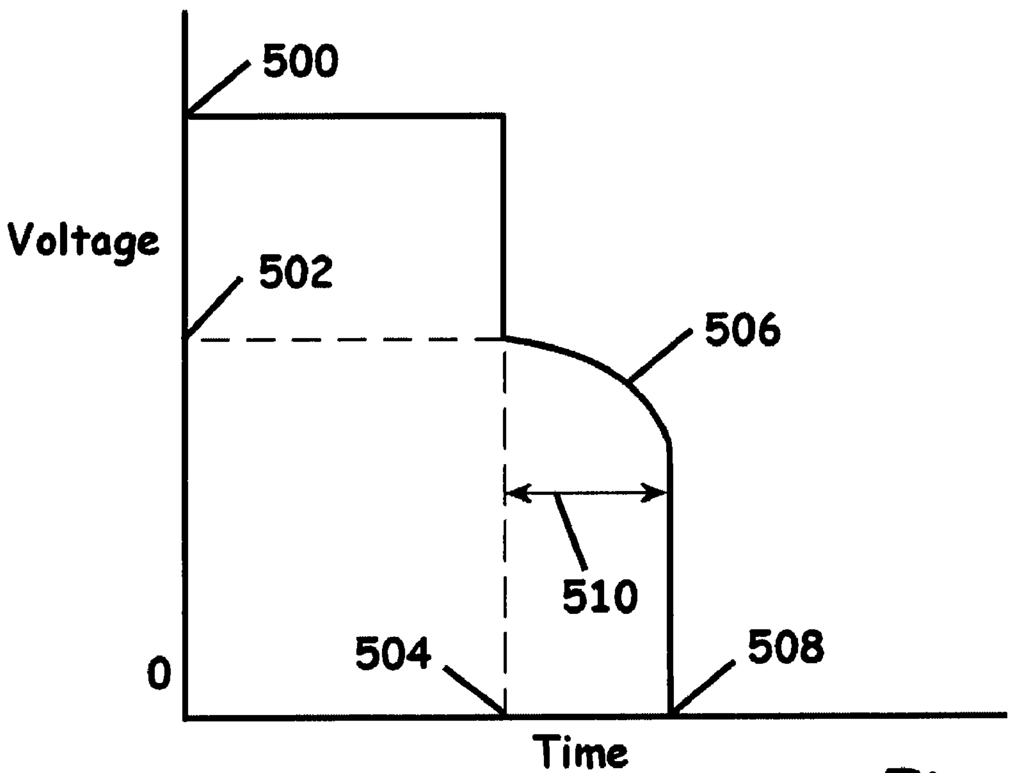

Fig. 5

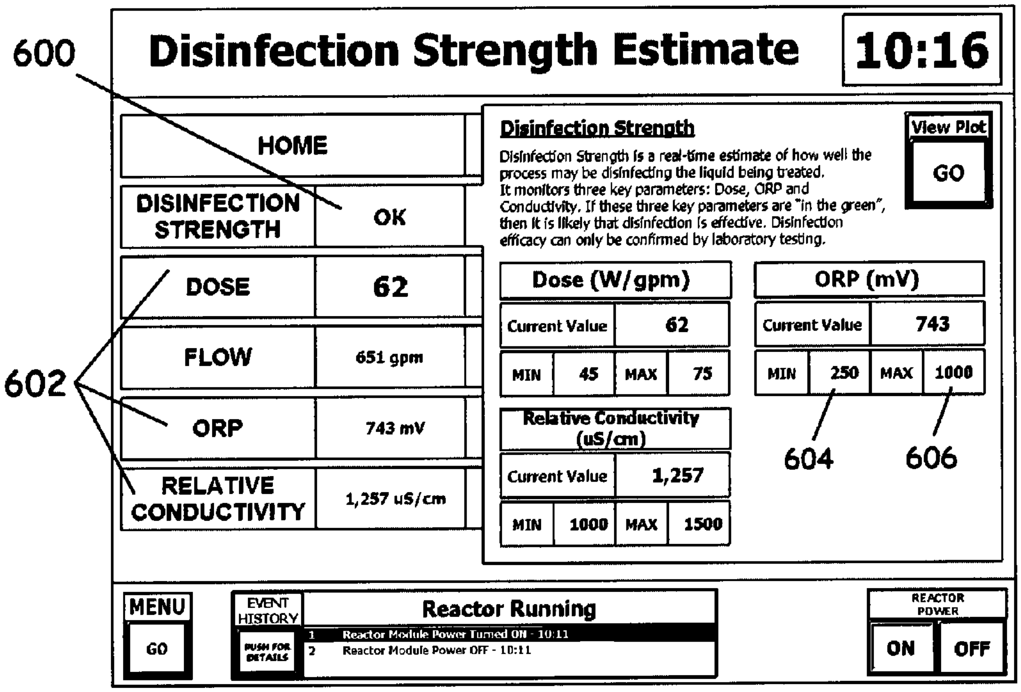
600
Disinfection Strength Estimate
10:16
HOME
DISINFECTION STRENGTH
OK
DOSE
62
FLOW
651 gpm
ORP
743 mV
RELATIVE CONDUCTIVITY
1,257 uS/cm
602
Disinfection Strength
Disinfection Strength is a real-time estimate of how well the process may be disinfecting the liquid being treated.
It monitors three key parameters: Dose, ORP and Conductivity. If these three key parameters are "in the green", then it is likely that disinfection is effective. Disinfection efficacy can only be confirmed by laboratory testing.
View Plot
GO
Dose (W/gpm)
Current Value
62
MIN
45
MAX
75
ORP (mV)
Current Value
743
MIN
250
MAX
1000
Relative Conductivity (uS/cm)
Current Value
1,257
MIN
1000
MAX
1500
604
606
MENU
GO
EVENT HISTORY
PUSH FOR DETAILS
Reactor Running
1 Reactor Module Power Turned ON - 10:11
2 Reactor Module Power OFF - 10:11
REACTOR POWER
ON
OFF

Fig. 6

ELECTROCHEMICAL LIQUID TREATMENT SYSTEM USING DOSE CONTROL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application 61/248,077 filed Oct. 2, 2009 hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to an apparatus and method of controlling the power delivered to an electrochemical process taking place in a treatment cell so that each unit volume of liquid passing through the treatment cell receives the same specified treatment dose, which dose may be a specified amount of electrical energy or electrical current, sometimes both. The invention also includes an apparatus and method which may modify the treatment dose based on chemical sensor measurements such as those for oxidation-reduction potential, calculated apparent liquid conductivity in the electrochemical cell, or other parameters.

[0003] Electrochemistry is a basis for many industrial processes. Some of these occur in fixed baths, such as electroplating applications, wherein a tank contains a conductive solution, the electrolyte, in which the desired coating material is either dissolved in the conductive solution itself or is on the surface of an electrode. This electrode, the anode, is connected to the positive terminal of a direct current power supply. The part to be plated is attached to the negative terminal of the power supply and becomes a cathode in an electrochemical reaction that takes place once the part is submerged in the electrolyte. Ions from the coating material are attracted to the cathode where they are reduced to metal atoms on the part being coated, for example chrome on an automobile grill.

[0004] Another application of electrochemistry is to generate chemicals from liquids containing precursor compounds. One industrial application, the chlor-alkali process, treats highly concentrated sodium chloride salt water by DC electrolysis to generate chlorine gas at the anode and a sodium hydroxide solution at the cathode. Such applications are not plating ones, so the anodes may be made out of conductive carbon or catalytic metal oxide surfaces, generally from the platinum group metals, and the cathodes can be conductors such as iron, mild steel, stainless steel or similar materials. In applications like this, the treatment cell may have an inlet and outlet to permit a process loop whereby salt is replenished in the water and is returned to the treatment cell to maintain the reaction.

[0005] In yet another electrolysis application, similar in many ways to the second one, a clean salt solution is circulated through a treatment cell to generate chlorine species, which include the hypochlorite ion and hypochlorous acid. This solution is then injected into another liquid stream and the chlorine species disinfect bacteria and other pathogens contained therein. These devices are commonly called hypochlorite generators.

[0006] In all of these applications, the magnitude of electrical current controls the reaction rate. The mass of metal that deposits on the cathode or the quantity of chemicals generated is directly proportional to the number of electrons provided by the power supply. For example, sodium chloride salt (NaCl) is a strong electrolyte that completely ionizes when dissolved in water. This NaCl solution will conduct electricity due to the mobility of the positive cations (Na+) and negative anions (Cl−). This ionization is represented by:

$$NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$$

[0007] The anion (Cl^-) is attracted to the treatment cell anode, or positively charged plate, where chloride ions are oxidized (donate electrons) to form chlorine gas as follows.

$$2Cl^- \rightarrow Cl_2(g) + 2e^-$$

[0008] One ampere of electrical current is equivalent to 6.242×10^{18} electrons per second. To generate chlorine, the anode donates two electrons to form one molecule of chlorine gas.

$$\frac{6.242\times10^{18}\frac{\text{electrons}}{s}}{2\frac{\text{electrons}}{Cl_2}} = 3.121\times10^{18}\frac{Cl_2}{s} = 1\text{ ampere}$$

$$Cl_2 = 70.9\text{ g/mole}$$

$$1\text{ mole} = 6.02\times10^{23}\text{ molecules } (\textit{Avagadro's}\text{ number})$$

$$\frac{70.9\text{ g}}{1\text{ mole}}\cdot\frac{1\text{ mole}}{6.02\times10^{23}\text{ molecules}}\cdot\frac{3.121\times10^{18}\text{ molecules}}{1s} = 367.6\times10^{-6}\text{ g/s} = 0.3676\text{ mg/sec}$$

[0009] Assuming 100% efficiency and non-reversible reactions, approximately 0.37 mg of chlorine gas will be created each second for each ampere. In reality, the electrochemistry of chlorine generation is more complicated because many parallel reactions may take place in the liquid being treated. For example, some of the electrical energy in a salt solution may be used to oxidize water and generate oxygen. In addition, for each oxidation reaction that takes place at the anode, an equal reduction reaction takes place at the cathode. For example, when water is oxidized to generate oxygen on the anode, hydrogen is evolved on the cathode. Efforts to optimize efficiency have led to the development of various metal oxide formulations used to coat the anodes that favor one reaction over another.

[0010] Since current and not power determines the rate of the electrochemical reactions, in almost all disinfection applications to date the electrode plates have been placed very close together to reduce resistive losses across the electrolyte between the electrode plates. Liquids with suspended solids cannot be treated at all without fine filtration beforehand, and those with significant dissolved solids could not be treated due to the rapid fouling of the electrodes from charged elements, compounds, proteins and other organic and inorganic matter.

[0011] Many electrochemical liquid treatment processes exist, including electrowinning, electrocoagulation, electroflocculation, electroprecipitation, and electrooxidation. One specific liquid treatment application of electrochemistry focuses on a direct current process to generate sodium hypochlorite and hypochlorous acid in a very clean salt water stream. These chemicals are disinfectants and oxidizing agents. The treated liquid is then injected into a dirty or contaminated liquid such as ship bilge water to disinfect and oxidize the contaminants contained therein. The described electrolytic reaction takes place in a liquid that normally has relatively constant salinity and conductivity along with a relatively constant flow rate.

[0012] Traditionally, the direct current power used in such electrolytic applications has been controlled in a relatively simple manner. Over time equipment manufacturers have determined an optimum current density for a particular anode material and application that balances production rate with anode life. Knowing this and the conductivity of the liquid in the treatment cell, a voltage can be set to deliver this current density. If these systems experience an increase in the flow rate through the treatment cell, the power delivered will remain unchanged and will cause an equivalent reduction in the energy delivered to each unit volume of the flow. This can result in reduced treatment efficacy, such as disinfection and oxidation of the contaminants in the flow streams. If the flow rate were to go down, unplanned overtreatment of the liquid stream would take place, wasting energy and perhaps causing other undesired changes in the liquid. The net result in flow variations is uneven treatment of the liquid.

SUMMARY OF THE INVENTION

[0013] The invention herein provides an apparatus and method of automated control of an electrochemical process, referred to as "dose control", which is designed to modulate the power delivered to an electrolytic flow-through treatment cell so that each unit volume of liquid passing through the treatment cell receives a specified uniform dose of electrical energy. Dose control may be used with alternating current, direct current, polarity switched direct current, or pulse width modulated current power supplies.

[0014] The inventors have determined that treatment efficacy for a liquid stream is directly proportional to the energy delivered to a given volume of liquid and this energy level varies by the specific properties of the liquid stream being treated. As such, if the flow rate or liquid conductivity changes, the applied power must be adjusted to maintain the predetermined dose of energy to each unit of liquid volume.

[0015] Dose is defined as power divided by flow. One way to express it is as a kilowatts (kW) per million gallons (mgal) per day or kW/mgd. This can be expressed simply by the following equations:

$$\text{Dose}\left(\frac{\text{kW}}{\text{mgd}}\right) = \frac{\text{Power}}{\text{flow}} = \frac{V * I}{1.44 * \text{gpm}}$$

$$\text{Power} = \text{kW} \Rightarrow \frac{W}{1000} = \frac{V * I}{1000}$$

$$\text{Flow} =$$

$$\text{mgd} \Rightarrow \frac{\text{gallons}}{\text{min}} * \frac{1}{1/1440\ \text{day}} = \frac{1440}{\text{day}} * \frac{M\ \text{gallons}}{10^6} = .00144\ \text{mgd}$$

$$\text{Flow} \Rightarrow .00144 * \text{gpm} = \text{mgd}$$

[0016] Power supplies well known in the art can be controlled by setting boundary limits for output voltage (V) and current (I). The impedance of the load (R) determines whether the unit is voltage or current controlled. Under dose control, the current limit is set to a high level and is allowed to follow the non-linear impedance of the electrochemical treatment cell. The set voltage corresponds to the desired dose by the following relation.

$$\text{Voltage(V)} = \sqrt{\text{Dose} * gpm * R * 1.44}$$

[0017] A microprocessor or other controller receives information from process sensors, calculates the voltage required to maintain the delivery of the desired energy dose to the liquid stream as the flow varies, and adjusts the power supply to deliver this voltage.

[0018] It is thus a feature of at least one embodiment of this invention to control an electrochemical process to maintain a predetermined amount of energy delivered to each unit of liquid volume under varying conditions of operation.

[0019] Traditionally, electrochemical processes have been controlled to maintain a fixed level of current in a liquid stream. Yet many industrial liquid streams may vary significantly in flow rate during the course of operation. For example, in food processing liquid streams with inline strainers, flow goes down as solids build up on the strainer screens, increasing their pressure drops. Two strainers may be installed in parallel with one running at a time, and operators may suddenly switch over to the clean strainer so that they can clean the dirty one. This can cause flow to suddenly increase again. Any electrochemical treatment of such liquid streams, for example disinfection, could suddenly have reduced efficacy due to the additional flow. Raising power to avoid this would waste energy and compromise the lifetime of the electrodes.

[0020] It is thus a feature of at least one embodiment of this invention to use a flow measurement means to adjust the power delivered to the electrodes to maintain a predetermined dose to each unit of liquid volume of the liquid being treated irrespective of flow rate.

[0021] The impedance of an electrochemical treatment cell and thus the apparent conductivity is not constant. Depending on the electrode materials, especially catalytic electrodes, the treatment cell may not conduct electricity at all until a certain critical minimum voltage is reached. Once the voltage reaches this level, the electrodes will begin to conduct. As the voltage and corresponding current density increase and gases evolve from the electrodes, the apparent conductivity may continue to change.

[0022] The impedance of the treatment cell is calculated using measured values of voltage and current together with Ohm's law. The inverse of impedance is called conductance. The conductivity of the treatment cell can be calculated using this conductance combined with the treatment cell geometry factor. A treatment cell geometry factor is calculated using the electrode plate area (A), the distance between each electrode plates (d), and number of treatment channels (N) in the cell and will be different depending on the electrode configuration. For example, if alternating electrodes are each connected to opposite polarities of the power supply in a monopolar configuration, the treatment cell geometry factor is calculated as follows.

$$\text{treatment cell geometry factor} = \frac{d}{A \cdot N}$$

[0023] If only the end electrodes are connected to the power supply with unconnected electrodes in between in a bipolar configuration, the treatment cell geometry factor is calculated as follows.

$$\text{treatment cell geometry factor} = \frac{d \cdot N}{A}$$

[0024] For a hybrid monopolar/bipolar configuration, a combination of the above equations would be used to calculate the treatment cell geometry factor.

[0025] Once the treatment cell geometry factor is calculated, it can be used to calculate the apparent conductivity as follows.

Apparent conductivity=treatment cell geometry factor×conductance

[0026] It is important to note that this conductivity, as measured within the treatment cell and referred to as the apparent conductivity, may be significantly different from that measured outside the treatment cell, referred to herein as the inherent conductivity.

[0027] As an additional complication, commercial liquid streams may vary in conductivity quite significantly over time as organic and inorganic loads change. This can have a dramatic effect on the actual treatment dose delivered if not otherwise corrected.

[0028] It is thus a feature of at least one embodiment of this invention to directly calculate the apparent conductivity in the treatment cell and use this to adjust voltage and current to maintain the desired dose to each unit of liquid volume of the liquid being treated.

[0029] As described earlier, for certain electrode materials, especially catalytic electrodes, electrical current may not begin to flow in the treatment cell until a certain minimum voltage is reached, called the activation voltage.

[0030] The activation voltage can vary depending on temperature, liquid property variations and for other reasons and operating near this limit can result in highly varied dose delivery. Consistent control of dose delivery is very difficult to do if the desired dose requires operating close to the activation voltage.

[0031] Pulse width modulation is a technique that turns power on and off for fractions of a second at a time on a repeated basis to modulate current flow and power use while avoiding the need to adjust voltage. Many incandescent light dimmers use this technique.

[0032] The inventors have determined that pulse width modulation provides a robust method of maintaining a consistent treatment dose when continuous power delivery otherwise would require operating at voltages close to the activation limit. Voltages are set somewhat higher than the activation voltage and the width of the "on" time pulse is adjusted to deliver the treatment dose desired.

[0033] It is thus a feature of at least one embodiment of this invention to use pulse width modulation to permit the delivery of a consistent low treatment dose while maintaining electrode voltage above the activation voltage.

[0034] The invention further relates to methods of recording and reporting various operating parameters on a display screen, printed report or database so that an estimate of process efficacy, specifically disinfection efficacy is provided, which may not otherwise be available on an online basis due to the laboratory delays associated with such tests. Depending on the process liquid being treated, several key parameters can be monitored and integrated to make this process efficacy estimate.

[0035] Regulating bodies such as the U.S. Department of Agriculture and Food and Drug Administration monitor the food safety controls used by food processors. They need to know what steps plants are taking to control pathogens. They also need to know if the intervention is working or not. Unfortunately there is no online measurement for bacteria count, and lab tests take 24-48 hours to provide accurate disinfection results.

[0036] It is thus a feature of at least one embodiment of this invention to monitor key parameters including, but not limited to; treatment dose, liquid flow rate, oxidation reduction potential, apparent conductivity, and chlorine levels. Acceptable operating ranges for each parameter can be set. If the parameter falls out of the acceptable range, the user will be notified by visual and audible means. If necessary, the microcontroller can control external chemical disinfectant pumps as a failsafe measure.

[0037] These particular objects and advantages may apply to only some embodiments falling within the claims and thus do not define the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0038] FIG. **1** is a perspective view of a liquid treatment system in one embodiment of the present invention showing a main housing holding opposed planar electrodes between liquid inlets and outlets, a power distribution module, and a control unit;

[0039] FIG. **2** is a detailed block diagram of the components of FIG. **1** showing the electrodes as flat plates;

[0040] FIG. **3** is a graph showing the voltage and current curves of electrically conductive catalytic electrodes;

[0041] FIG. **4** illustrates pulse width modulation techniques;

[0042] FIG. **5** illustrates the capacitive effect of electrode plates upon removal of power from these plates; and

[0043] FIG. **6** shows a touchscreen interface displaying a real-time estimate of treatment efficacy.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0044] Referring now to FIGS. **1** and **2**, a liquid treatment system **10** per the present invention may include a treatment unit **12** providing a liquid inlet **14** and outlet **16** to conduct liquid across internal electrodes **28**. The electrodes **28** are contained in an insulating housing **18** supported on frame **20** and may be, for example, carbon, metals such titanium or stainless steel or the like, and optionally coated with catalytic materials such as platinum group metal consisting of platinum, palladium, rhodium, iridium, osmium, and ruthenium, or similar materials.

[0045] A power distribution module **22** provides electrical connections **24** to the internally contained electrodes **28** for power received from a control unit **26**. The control unit **26** has a touchscreen user interface **27** for the display and entry of data including critical operation parameters.

[0046] Referring now to FIG. **2**, the treatment unit **12** includes two or more generally planar and parallel electrodes **28** held in a channel **36** between the inlet **14** and the outlet **16**. The electrodes **28** are separated along an axis **30** generally perpendicular to the flow of liquid by gaps **32** to receive liquid **34** therethrough. The separation of the electrodes **28** will be greater than 5 mm to permit the passage of untreated liquid **34** without undue risk of clogging.

[0047] One or more chemical sensors **40** may be positioned in sensor fitting **38** downstream from the electrodes **28** and channel **36** to measure chemical properties of the liquid and/or a flow sensor **42** may be positioned in the stream of liquid **34** to measure the flow across the electrodes **28**. The chemical sensors **40** may include those measuring pH, oxidation-reduction potential, chlorine level, free chlorine level, or total chlorine level.

[0048] The amount of flow through the channel **36** may be controlled by an electrically driven pump **44** and/or valve **46** alone or in combination.

[0049] The electrodes **28** are electrically isolated from each other as held by the housing **18** but may be joined by the connections **24** from power distribution module **22** so that some or all of the electrodes **28** are electrically connected to electrical conductors **48*a*** and **48*b***. In some configurations alternating electrodes may be connected to opposite power polarities. In other configurations some electrodes **28** may not be directly connected to the electrical conductors **48*a*** and **48*b*** but instead become electrically activated by the ionic currents in the liquid **34** being treated, resulting in each side of such intermediate electrodes **28** having opposite polarities, an arrangement known as bipolar mode.

[0050] Conductors **48*a*** and **48*b*** are connected to a switching unit **50** contained in the control unit **26** that may alternate the electrical polarity or limit the current to the electrodes **28**. The switch is depicted logically as a double pole, triple throw electrical switch and will be typically implemented by solid-state electronics controllable by control line **51**. One pole connects to a positive voltage line **52** from a voltage controllable DC power supply **58** and the other pole connects to a negative voltage line **53** from the voltage controllable DC power supply **58**. The voltage controllable DC power supply **58** receives power from electrical mains **62**.

[0051] The throws of the switching unit **50** are controllable so that one conductor **48*a*** or **48*b*** may be connected to a given voltage (positive or negative) while the other conductor **48*a*** or **48*b*** is connected to the opposite voltage. The switching unit may also limit the power delivered to the electrodes by modulating at a specific frequency and duty cycle.

[0052] The positive voltage line **52** may connect to a current sensor **54** and voltage sensing point **56**, both of which are connected to inputs of a controller **60**, the latter being a special-purpose computer, for example, a programmable logic controller executing a stored program to control of the process as will be described. A similar current sensor **54** and voltage sensing point **56** (not shown) may be provided on negative voltage line **53**. Sensors **52** and **54** may also be built into the power supply **58**. The programmable controller **60** also receives signals from the chemical sensors **40** and flow sensor **42** and may provide control signals to the pump **44** and valve **46**. In addition, the controller **60** communicates with the touchscreen **27** or alternative user input device which may be a keyboard or other means known in the art.

[0053] The controller **60** includes a processor **70** and a control program **72**, the latter contained in the memory **81** communicating with the processor **70** as is generally understood in the art. In operation, the program **72** will read various parameters of the process including the electrode current from current sensors **54**, the electrode voltage from voltage sensing points **56**, user entered parameters through touchscreen **27**, chemical environment sensing from the chemical sensors **40**, and/or the flow rate from the flow sensor **42**, and will provide output signals on control line **51** controlling the switching unit **50** and the power supply **58**. In addition, output signals controlling the pump **44** and valve **46** and providing information on the touchscreen **27** may be provided.

[0054] Pump **44** or the valve **46** may be used as the flow controller. Pump **44** may be a variable flow pump and valve **46** may be a continuously adjustable valve.

[0055] The control program **72** run by the processor **70** is designed to maintain a specified dose to the liquid being treated. The user provides basic setup by entering on the touchscreen **27** two key pieces of information, desired treatment dose and initial apparent conductivity. The initial apparent conductivity is used by the control program **72** as a default value if the calculated value falls out of a valid range or when the system starts. Dose is the controlling parameter in the system. The control program utilizes dose, flow, and apparent conductivity to determine the voltage or current to apply. Dose may be set as a given power, current or voltage or any of these measures on a per volume of flow basis. Further, dose may be adjusted over time based on other sensor readings indicating efficacy of the dose.

[0056] The power supply **58** can be either voltage or current controlled. If voltage controlled, the current is allowed to float within a range depending on the impedance of the treatment unit **12** to provide a given voltage across the liquid. If current controlled, voltage is allowed to float to maintain the desired current level through the liquid.

[0057] Referring now to FIG. **2**, FIG. **3** and FIG. **4** together, when the desired treatment dose would otherwise require a voltage at the electrodes below or only somewhat above the activation voltage **302** of the electrode plates (determined by the chemical composition of the plates as is understood in the art), the controller **60** uses pulse width modulation **400** to maintain voltage on the electrode at a minimum voltage that is somewhat greater than the activation voltage **302** of the electrode plates **28**.

[0058] Referring now to FIG. **3**, graph line **300** shows the idealized activation voltage curve, with no current flowing until activation voltage **302** is reached. Thereafter current rises in a linear fashion with voltage increases. Graph line **304** shows the actual curve of an approximate 50% saturated brine solution from the work of the inventors.

[0059] Referring to FIG. **4**, this graph provides a simplified view of pulse width modulation, which can take several forms and this invention is not intended to be limited by this illustrative figure. Graph line **400** illustrates pulse width modulation where the power is on 10% of the time. This power-on time is referred to as the duty cycle. This would allow the voltage to be set an appropriate level above the activation voltage to provide stable power delivery level while delivering only approximately 10% of the treatment dose that would be delivered with continuous power delivery at that voltage. Graph lines **402** and **404** illustrate 50% and 90% duty cycles, which would deliver a corresponding higher dose at the same voltage.

[0060] Referring now to FIG. **2**, FIG. **4** and FIG. **5** together, the inventors have determined that when voltage **500** is removed at time **504** from the electrode plates **28**, the electrical circuit maintains the voltage on the electrode plates **28** near the activation voltage **502** for a period of time after power has been removed from the electrodes. The voltage discharge follows a capacitive discharge curve **506** until the voltage goes to zero at time **508**. The time period of this capacitive discharge **510** is input via touchscreen **27** or obtained from a database. Control program **72** adjusts the frequency of pulse width modulation **400** so that the time with no power applied to electrode plates **28** during the pulse width modulation duty cycle does not fully discharge the electrode plates to avoid ramp up time delays at the start of the next duty cycle and reduces voltage shock effects on the electrode plates that could adversely affect electrode plate life.

[0061] The control program **72** constantly reads and records data from field and locally mounted devices. It filters this data and feeds it back into the equations controlling the voltage or current out. Power is constantly adjusted in this manner to maintain the set dose regardless of flow rate or conductivity.

[0062] Referring now to FIG. **6**, this is an example of a touchscreen **27** display of online estimated process efficacy. This is meant to be an illustrative example only and is not meant to limit the claims. This screen provides a real-time estimate of the disinfection efficacy, shown here as disinfection strength **600**, of the electrochemical process. In this specific case three variables **602** are used in the calculation: oxidation reduction potential (ORP), treatment dose, and relative (apparent) conductivity of the liquid being treated.

[0063] ORP indicates the ability of a liquid stream to oxidize the liquid. This is directly related to disinfection power for a given liquid stream and salinity level. A minimum level **604** and a maximum level **606** are set. Below the minimum, effective treatment becomes marginal. Above the maximum and unwanted byproducts may be produced, such as trichloramines which can cause negative effects on plant operators.

[0064] Treatment dose is the energy requirement per unit of volume that in the past has been demonstrated to deliver consistently acceptable disinfection results. It confirms that the power supply is operating properly. As with ORP, a minimum value is set as well as a maximum, above which power would be wasted or that may indicate a faulty sensor.

[0065] For a given liquid stream, changes in relative (apparent) conductivity substantially relates to changes in the salinity or chloride content of the liquid. If salinity were to drop, the balance between molecular oxygen, reactive oxygen species, and reactive chlorine species would change, affecting disinfection performance. If the salinity level were to rise too high, unwanted byproducts such as trichloramines may be produced.

[0066] The control program for online process efficacy monitors whether the selected variables **602** are in the acceptable range and displays an estimate of disinfection strength **600** of "OK" or language with a similar meaning if all three are in range. In addition, the disinfection strength indicator **600** and the variables all have a green background to provide a quick indicator of system efficacy to plant personnel who may be at a distance.

[0067] If one or more variables **602** falls or rises outside of the range determined by the minimum value **604** and maximum value **606** but does so by less than a predetermined amount or percentage, such as ten percent, the indicator for that variable **602** changes color to yellow and the disinfection strength indicator **600** changes to yellow. The disinfection strength indicator also changes text to read "LOW" or to language with a similar meaning. Again, this color change permits plant operators to monitor expected process efficacy and operational status at a distance.

[0068] Finally, if one or more of the variables **602** falls or rises by more than the predetermined amount or percentage described previously, such as the ten percent in the example, the indicator for that variable **602** changes color to red and the disinfection strength indicator **600** changes to red. The disinfection strength indicator also changes text to read "VERY LOW" or to language with a similar meaning. The red color may also blink. Again, this color change permits plant operators to monitor expected process efficacy and operational status at a distance. In some installations a warning horn may also be sounded to draw attention to the out of limits condition.

[0069] The inventors do not intend to limit this control methodology to minimum and maximum set points, and the use of intermediate (marginal performance) set points has already been tested. The inventors also envision control programs that adjust one monitored variable in response to changes in another, such as increasing treatment dose if relative (apparent) conductivity levels fall.

[0070] The present invention has been described in terms of the preferred embodiment, and it is recognized that equivalents, alternatives, and modifications, aside from those expressly stated, are possible and within the scope of the appending claims.

We claim:

1. A liquid treatment system comprising
- a treatment cell containing at least two electrodes through which a liquid to be treated may flow;
- a power supply providing power to the electrodes;
- at least one sensor to measure at least one parameter of the liquid being treated and providing sensor data on that parameter; and
- a control system that adjusts power delivered to the treatment cell based upon the sensor data.

2. The liquid treatment system of claim **1** further including a flow meter measuring treatment liquid flow and wherein the control system adjusts the power delivered to the treatment cell to provide a predetermined dose of energy to each volume element of the liquid stream being treated.

3. The liquid treatment system of claim **1** further including a flow meter measuring treatment liquid flow and wherein the control system adjusts the power delivered to the treatment cell to provide a predetermined dose of current to each volume element of the liquid stream being treated.

4. The liquid treatment system of claim **1** wherein the at least one sensor measures a voltage and current delivered to the treatment cell, and
- wherein the control system calculates an apparent conductivity of the liquid in the treatment cell and adjusts the power delivered to the treatment cell to provide a predetermined dose of energy to each volume element of the liquid stream being treated.

5. The liquid treatment system of claim **1** wherein the at least one sensor measures a voltage and current delivered to the treatment cell, and
- wherein the control system calculates an apparent conductivity of the liquid in the treatment cell and adjusts the power delivered to the treatment cell to provide a predetermined dose of current to each volume element of the liquid stream being treated.

6. The liquid treatment system of claim **1** wherein the at least one sensor measures liquid properties selected from the group consisting of oxidation-reduction potential, salinity, chlorine concentration, and pH provide sensor data to the control system to adjust the power applied to the electrodes for treatment of the liquid.

7. A method of controlling electrical power delivered to electrodes in an electrochemical liquid treatment system of a type providing a treatment cell containing at least two electrodes through which a liquid to be treated may flow, a power supply providing power to the electrodes; and at least one sensor to measure at least one parameter of the liquid being treated to provide sensor data on that parameter; the method comprising the steps of:

passing a liquid through the electrochemical treatment cell;

monitoring at least one parameter of the liquid being treated with a sensor to provide sensor data;

adjusting the power delivered to the treatment cell based upon the sensor data.

8. The method of claim 7 wherein the liquid treatment system further includes a flow measuring device and wherein the method adjusts the power delivered to the treatment cell to provide a predetermined dose of energy to each volume element of the liquid stream being treated.

9. The method of claim 7 wherein the liquid treatment system further includes a flow measuring device and wherein the method adjusts the power delivered to the treatment cell to provide a predetermined dose of current to each volume element of the liquid stream being treated.

10. The method of claim 7 further including the steps of:

monitoring voltage and current delivered to the treatment cell,

calculating an apparent conductivity of the liquid in the treatment cell, and

wherein the step of adjusting, modulates the power delivered to the treatment cell to provide a predetermined dose of energy to each volume element of the liquid stream being treated.

11. The method of claim 7 further including the steps of:

monitoring voltage and current delivered to the treatment cell,

calculating an apparent conductivity of the liquid in the treatment cell, and

wherein the step of adjusting, adjusts the power delivered to the treatment cell to provide a predetermined dose of current to each volume element of the liquid stream being treated.

12. The method of claim 7 wherein the step of adjusting modulates an electrical dose delivered to a liquid in a treatment cell based on sensor information selected from the group consisting of oxidation-reduction potential, treatment liquid salinity, chlorine measurements, and pH.

13. A method of providing a real-time estimate of treatment efficacy of an electrochemical process comprising the steps of:

passing a liquid through an electrochemical treatment cell;

monitoring at least two parameters selected from the group consisting of: power delivery and liquid characteristics;

calculating and reporting an estimate of treatment efficacy based on the parameters measured.

14. The method of claim 13 wherein treatment efficacy is estimated based on at least two process parameters from the group consisting of: dose delivered to the liquid, oxidation reduction potential of the liquid and an apparent conductivity of the liquid in the treatment cell.

15. The method of claim 13 wherein an expected effective treatment performance operating range for least one process parameter is determined by a use of minimum and maximum setpoints for the range.

16. The method of claim 13 wherein a marginally effective treatment range is determined as a variance from a minimum and maximum setpoints.

17. The method of claim 13 wherein a marginally effective treatment range is established through a use of at least one setpoint.

18. The method of claim 13 wherein a color change on at least one element of a user interface is used to indicate a change in an expected liquid treatment process efficacy.

19. The method of claim 13 wherein an alarm is provided based on a change in the expected liquid treatment process efficacy.

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