

ELECTROLYSIS SYSTEM

PRIORITY CLAIM

[0001] The present application claims priority from 63/521,779, filed in the United States of America on 19 June 2023. The contents of the priority application are hereby incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates generally to the field of electrolysis, and more specifically to variable-power plasma electrolysis.

BACKGROUND

[0003] Developing a sustainable, scalable and efficient hydrogen source represents an important goal, particularly in power and energy industries. A primary source of hydrogen is water electrolysis, the splitting of water into hydrogen and oxygen ions which then react to produce hydrogen and oxygen gas.

[0004] Prior art systems for water electrolysis are inefficient, prone to overheating, or require that the water contain high concentrations (> 10% w/v) of bases such as potassium hydroxide in order to provide the necessary environment.

[0005] The present invention aims to alleviate, reduce or ameliorate one or more of the problems within prior art systems.

DISCLOSURE OF THE INVENTION

[0006] In a first aspect, the present invention comprises an electrolysis system comprising a tank adapted to contain water or an aqueous solution, an electrolytic array comprising electrically conductive plates, a temperature-resistant cathode proximal to, but spaced apart from, a cathodic end of the electrolytic array, a tank anode proximal to, but spaced apart from, an opposing anodic end of the electrolytic array, wherein the cathodic and anodic ends of the electrolytic array are electrically connected to a negative and positive terminal, respectively, of a first power supply adapted to provide direct-current (DC) power thereto, the

temperature-resistant cathode and the tank anode are electrically connected to a negative and positive terminal, respectively, of a second power supply adapted to provide DC power thereto and at least the temperature-resistant cathode is adapted to generate a plasma arc within the water or aqueous solution between an end thereof and a closest plate of the electrolytic array.

[0007] In an embodiment, the plates of the electrolytic array are arranged into a plurality of combs, each comb having at least three plates, and each comb further comprises an electrically conductive comb spine extending therebetween and connecting the plates within that particular comb, such that the at least three plates of each comb are arranged along the comb spine to provide a cathodic end plate and anodic end plate, with at least one shield plate therebetween, the cathodic and anodic end plates being located closer to the cathodic and anodic ends of the electrolytic array, respectively.

[0008] In an embodiment, the electrolytic array is formed by sequentially arranging the plurality of combs between the temperature-resistant cathode and tank anode such that, for each particular comb in the sequence, the anodic end plate is at least partially interleaved between the cathodic end plate and the shield plate adjacent thereto of the following comb in the sequence, the cathodic end plate is at least partially interleaved between the anodic end plate and the shield plate adjacent thereto of the preceding comb in the sequence and substantially none of the combs in the sequence are in direct contact with one another.

[0009] In an embodiment, and for at least one of the plurality of combs, at least one of the cathodic end plate, anodic end plate, and at least one shield plate are shaped to increase edge length per unit volume.

[0010] In an embodiment, at least the second power supply is adapted to provide DC power as dirty DC power.

[0011] In an embodiment, at least the second power supply is adapted to provide DC power in pulses. In an embodiment, the second power supply provides DC power in pulses with a frequency between 1 – 100 Hz. In an embodiment, the first power supply is also adapted to provide DC power in pulses. In an

embodiment, the first power supply provides DC power in pulses with a frequency between 50 – 50,000 Hz

[0012] In an embodiment, the first and second power supplies provide DC power in pulses of substantially same frequency. In an alternative embodiment, the first and second power supplies may provide DC power in pulses of different frequencies. In an embodiment, there is a phase shift between the pulsed DC power provided by the first and second power supplies. In an embodiment, the phase shift is between approximately 45° and approximately 135°.

[0013] In an embodiment, the aqueous solution comprises water with a soluble base dissolved therewithin. In an embodiment, the soluble base is a hydroxide. In an embodiment, a concentration of the soluble base in the aqueous solution is equivalent to potassium hydroxide dissolved in the water at a concentration between 0 – 5% weight per volume (% w/v).

[0014] In an embodiment, the system further comprises a vibrating means.

[0015] In an embodiment, the temperature-resistant cathode is partially encased in an insulating sleeve extending for a substantial majority of at least a submerged portion thereof, the end of the temperature-resistant cathode is not encased by the insulating sleeve and is exposed to contact the water or aqueous solution, and the insulating sleeve is shaped to inhibit generation of the plasma arc between portions of the temperature-resistant cathode other than the end thereof and the closest plate of the electrolytic array.

[0016] Further or alternative embodiments of the invention may be disclosed herein or may otherwise become apparent to the person skilled in the art through the disclosure herein. These and other embodiments are considered to fall within the scope and object of the invention.

DESCRIPTION OF FIGURES

[0017] Embodiments of the present invention will now be described in relation to figures, wherein:

Figure 1 depicts an embodiment of an electrolysis system of the present invention; Figure 2 depicts an embodiment of the same comprising an electrolytic array utilising combs;

Figures 3-5 depict various example embodiments of combs of the present invention;

Figure 6 depicts various example embodiments of plates of the present invention;

Figure 7 is an oscilloscope waveform reading of an embodiment of the present invention; and

Figure 8 depicts an embodiment of the present invention comprising a vibrating means and an insulating sleeve.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0018] In an embodiment and with reference to Figure 1, the present invention may lie in an electrolysis system 10, for the electrolysis of water into hydrogen and oxygen gas, comprising a tank 12 that is adapted to contain water or an aqueous solution. Within the tank 12 are a tank anode 14 and a temperature-resistant cathode 16, each being spaced apart from one another. An electrolytic array 18 is arranged within the tank 12 between the tank anode 14 and temperature-resistant cathode 16, and is further arranged such that upon the tank being filled with water, the electrolytic array is submerged thereby. In an embodiment, the electrolytic array 18 comprises a plurality of electrically conductive plates. In an embodiment, the temperature-resistant cathode 16 is arranged proximal to, but spaced apart from, a cathodic end 18A of the electrolytic array 18, while the tank anode 14 is arranged proximal to, but spaced apart from, an opposing anodic end 18B. In an embodiment, the cathodic and anodic ends 18A, 18B of the electrolytic array 18 are electrically connected to a negative and positive terminal, respectively, of a first power supply 20 that is adapted to provide direct-current (DC) power thereto. In an embodiment, the temperature-resistant cathode 16 and the tank anode 14 are electrically connected to a negative and positive terminal, respectively, of a second power supply 22 that is adapted to provide DC power thereto.

[0019] In an embodiment, the electrolytic array 18 is not in direct electrical connection with the temperature-resistant cathode 16. In an embodiment, the electrolytic array 18 is not in direct electrical connection with the tank anode 14.

[0020] In an embodiment, the temperature-resistant cathode 16 may be adapted to, upon being powered, generate a plasma arc 24, within the water or aqueous solution between an end thereof and the closest plate of the electrolytic array 18. The closest plate will generally be arranged at the cathodic end 18A of the electrolytic array 18. In a further embodiment, the end of the temperature-resistant cathode 16 may be shaped to form a point. This may enable the plasma arc 24 to form at a lower temperature and/or voltage. In an alternative further embodiment, the end of the temperature-resistant cathode 16 may be shaped to provide a flat surface. While such an embodiment may increase the power required to generate a plasma arc 24, the formed plasma arc may have a larger volume and thus greater plasma front for driving electrolysis.

[0021] In an embodiment and with reference to Figures 2 - 5, the plates of the electrolytic array 18 may be arranged into a plurality of combs 26. In an embodiment and with particular reference to Figures 3 & 4, each comb 26 comprises at least three plates 28, and an electrically conductive comb spine 30 extending therebetween and connecting the plates within that particular comb. In a further embodiment, the at least three plates 28 of a particular comb are arranged along the comb spine 30 to provide a cathodic end plate 28A and an anodic end plate 28B, with at least one shield plate 28C therebetween. As the skilled person may appreciate, the comb 26 is arranged within the electrolytic array 18 such that the cathodic and anodic end plates 28A, 28B are located closer to the cathodic and anodic ends 18A, 18B of the electrolytic array 18, respectively. Figure 4 depicts various example forms of a comb of the present invention, including a single shield plate 28C as well as multiple shield plates 28C.

[0022] Without limiting the scope of the invention through theory, it is envisaged that grouping the plates 28 into combs 26 comprising a cathodic and anodic end plates 28A, 28B, with at least one shield plate 28C in-between and direct electrical connection therebetween provided by the comb spine 30, may enable the cathodic end plate 28A to remain consistently cathodic and the anodic end plate 28B to remain consistently anodic. As the skilled person will appreciate, the reaction of

water electrolysis leading to hydrogen and oxygen gas evolution is comprised of an anodic and cathodic half-reaction. In prior art electrolytic systems using plate stacks of alternating anodic and cathodic plates, each individual plate will develop a charge differential across its thickness, being more anodic on the side closest to the system anode and more cathodic on the side closest to the system cathode. This may be contrasted to at least the present embodiment, wherein it is anticipated that, while a charge differential will still develop, said charge differential will be dispersed across the length of the comb. It is further anticipated that, as a result, any such charge difference across a particular, specific plate 28 *within* a comb 26 will be substantially reduced, inhibited or otherwise ameliorated. This may in turn improve the efficiency of reactions occurring at each of the cathodic and anodic end plates 28A, 28B.

[0023] In an embodiment and with particular reference to Figures 2 & 5, the electrolytic array 18 may be formed by sequentially arranging the plurality of combs 26 between the temperature-resistant cathode 16 and tank anode 14 such that, for each particular comb 26- n in the sequence, the anodic end plate 28B $_n$ is at least partially interleaved between the cathodic end plate 28A $_{(n+1)}$ and the shield plate 28C $_{(n+1)}$ adjacent thereto of the following comb 26- $(n+1)$ in the sequence. Similarly, the cathodic end plate 28A $_n$ of the particular comb 26- n is at least partially interleaved between the anodic end plate 28A $_{(n-1)}$ and the shield plate 28C $_{(n-1)}$ adjacent thereto of the preceding comb 26- $(n-1)$ in the sequence. In a further embodiment, substantially none of the combs in the sequence are in direct contact with one another. In a further embodiment, the electrolytic array 18 may comprise membranous or spacer materials (*not depicted for clarity*) arranged to prevent the plurality of combs 26 from directly contacting one another. The skilled person will appreciate that the above arrangements only partially applies to the first and last combs 26 in the electrolytic array 18, as they do not have preceding or following electrolytic stacks, respectively.

[0024] In an embodiment and as depicted in Figure 2, the cathodic end 18 of the electrolytic array 18 may comprise an end comb 32 formed of a pair of plates 28 and a spine 30, with the cathodic end plate 28A of the adjacent comb 26 interleaved therebetween. In an embodiment, the anodic end 18 of the electrolytic array 18 may comprise an end comb 32 formed of a pair of plates 28 and a spine

30, with the anodic end plate 28B of the adjacent comb 26 interleaved therebetween.

[0025] In an embodiment and with reference to Figure 6, and for at least one of the plurality of combs, at least one of the cathodic end plate 28A, anodic end plate 28B, and at least one shield plate 28C may be shaped to increase edge length per unit volume. Without limiting the scope of the invention through theory, it has been surprisingly found that while increased surface area has some effect on reaction rate, increased edge length appears to potentially have a substantially greater effect. An increase in surface area and/or edge length may be achieved in a number of ways. Some non-limiting examples of means of providing an increase in surface area and/or edge length per unit volume are through provision of ridges, protrusions, fins, or similar structures, through shaping the plate 28 to have a tortuous perimeter, or forming apertures, openings or holes extending at least partway through the plate. Some examples of plates 28 being shaped to have increased surface area and/or edge length are depicted in Figure 6. Other means of increasing surface area and/or edge length per unit volume may exist within the common general knowledge of the art or may otherwise become clear to the skilled person through disclosure contained herewithin, and these and other means are considered to fall within the scope of at least the present embodiment of the invention.

[0026] In an embodiment, at least the second power supply 22 is adapted to provide DC power as dirty or fluctuating DC power. In a further embodiment, the dirty/fluctuating DC power may fluctuate in voltage, in amperage, or in both voltage and amperage. Without limiting the scope of the invention through theory, it is considered that providing fluctuating DC electricity may substantially increase the efficiency of electrolytic processes, in particular the electrolytic splitting of water into hydrogen and oxygen ions as driven by the plasma arc 24. Again without limiting the scope of the invention through theory, it is envisaged that the constantly fluctuating flow of electricity may cause the water molecules within or proximal to the plasma arc 24 to undergo a 'push-pull' process due to the constantly shifting electrical and magnetic environment, and it is further envisaged that this fluctuating 'push-pull' process may assist in splitting the water molecule into hydrogen and oxygen ions, thereby improving splitting efficiency.

[0027] In an alternative embodiment, at least the second power supply 22 may be adapted to provide DC power in pulses. The pulsing may comprise alternating between an 'on' state wherein power is supplied to the electrolysis system 10 and an 'off' state wherein power is not supplied to the electrolysis system 10. It is envisaged that provision of DC power in pulses may achieve a similar effect to that of 'dirty' or fluctuating power as described above.

[0028] Figure 7 is an oscilloscope reading of an embodiment of a system 10 of the present invention illustrating a voltage waveform of the electrolytic array 18 as DC power is pulsed between 'on' and 'off' states. Where a square waveform having sharp vertical rises and falls would be expected due to the DC power cycling or pulsing between 'on' and 'off' states, there is instead a waveform having the characteristic and expected sharp vertical rise of a square waveform, but the instead of the expected sharp vertical fall there is a curved slope that is more indicative or suggestive of a gradual release of stored energy. Without limiting the scope of the invention through theory and with reference to the waveform depicted in Figure 7, it is theorised that embodiments of the system 10 comprising an electrolytic array 18 that is formed of interleaved combs 26 may demonstrate momentary capacitive properties. In particular, it is theorised that, upon the pulse 'switching off', residual energy may be trapped within the plates 28, leading to the surprising and unexpected shape of the voltage waveform depicted in Figure 7. It is further theorised that this may allow for water to continue to be electrolysed and hydrogen and oxygen gas to continue to evolve during the 'off' stage of the pulse, thereby expending said trapped residual energy. An embodiment of the system 10 designed to operate with on-off pulsing of the plasma arc 24 formed by the second power supply 22 may therefore have an improved efficiency, as gaseous production continuing for a short period of time when no power is being supplied means overall power consumption is effectively reduced per unit volume of hydrogen or oxygen gas that is produced.

[0029] In a further embodiment, the second power supply 22 may provide DC power in pulses with a frequency between 1 – 100 Hz. In a further embodiment, the pulse frequency may be 50 Hz or less, 30 Hz or less, 25 Hz or less, 20 Hz or less, 15 Hz or less, or 10 Hz or less. In a further embodiment, the pulse frequency

may be 2 Hz or greater, 5 Hz or greater, 10 Hz or greater, 15 Hz or greater, 20 Hz or greater, or 30 Hz or greater.

[0030] In an embodiment, the first power supply may also be adapted to provide DC power in pulses. In a further embodiment, the first power supply 20 may provide DC power in pulses with a frequency between 50 – 50,000 Hz. In a further embodiment, the pulse frequency may be 45,000 Hz or less, 30,000 Hz or less, 25,000 Hz or less, 20,000 Hz or less, 15,000 Hz or less, 10,000 Hz or less, 5,000 Hz or less, 2,000 Hz or less, 1,000 Hz or less, 500 Hz or less, or 100 Hz or less. In a further embodiment, the pulse frequency may be 75 Hz or greater, 100 Hz or greater, 200 Hz or greater, 500 Hz or greater, 1,000 Hz or greater, 5,000 Hz or greater, 10,000 Hz or greater, 20,000 Hz or greater, 30,000 Hz or greater, or 40,000 Hz or greater.

[0031] In one further embodiment, the first and second power supplies 20,22 may provide DC power in pulses of substantially same frequency. In an alternative further embodiment, the first and second power supplies 20,22 may provide DC power in pulses of different frequencies.

[0032] In an embodiment, there is a phase shift between the pulsed DC power provided by the first and second power supplies 20,22. In a further embodiment, the phase shift may be between approximately 45° and approximately 135°. In a further embodiment, the phase shift may be between approximately 60° and approximately 120°. In a further embodiment, the phase shift may be approximately 90°.

[0033] In an embodiment, the provision of pulsing DC power may be achieved through the use of switches arranged to switch the particular electrical circuit between an 'on' and 'off' state. In a further embodiment, the switches may be voltage-controlled switches. In a further embodiment, the switches may be Insulated Gate Bipolar Transistor (IGBT) switches.

[0034] In an embodiment, the water may be distilled water, brackish water, groundwater, seawater or any other conventional water source. In a further embodiment, the water may be an aqueous solution with a soluble base dissolved

therewithin. In a further embodiment the soluble base may be a hydroxide, a carbonate or bicarbonate.

[0035] It is recognised that in the art, one of the most common hydroxides used in prior art electrolysis systems is potassium hydroxide. As such, it is considered appropriate to discuss embodiments of the present invention with respect to usage of potassium hydroxide for ease of technical interpretation. However, the person skilled in the art will appreciate that there are many other soluble bases that are suitable alternatives. Therefore, unless otherwise explicitly noted the scope of the present invention is not to be interpreted as being limited to the use of potassium hydroxide as the soluble base. The concentration of the soluble base will be provided as being equivalent to a given percentage weight per volume concentration of potassium hydroxide, and should be interpreted to mean that any suitable soluble base may be used, in a percentage weight per volume concentration that provides the same hydroxide ion concentration as the given value of potassium hydroxide.

[0036] In an embodiment, the concentration of hydroxide dissolved within the water may be equivalent to between 0 – 5% w/v potassium hydroxide dissolved in the water, wherein w/v means weight per volume.

[0037] It is understood that prior art systems typically utilise a concentration of approximately 20% w/v potassium hydroxide dissolved in water, and that this may promote substantial heat generation within the prior art system. It is considered that by reducing the concentration of potassium hydroxide may substantially ameliorate the problem of excess heat generation. In a further embodiment, the concentration of the soluble base in the water may be equivalent to 3% w/v potassium hydroxide or less, 1.5% w/v potassium hydroxide or less, 1% w/v potassium hydroxide or less, or 0.5% w/v potassium hydroxide or less. In a further embodiment, the concentration of the soluble base in the water may be equivalent to 0.1% w/v potassium hydroxide or greater, 0.3% w/v potassium hydroxide or greater, or 0.5% w/v potassium hydroxide or greater.

[0038] In an embodiment and with reference to Figure 8, the electrolysis system 10 may further comprise a vibrating means 34. The vibrating means 34 may be arranged to vibrate the tank 12, the water or aqueous solution, the electrolytic

array 18, or all three. The vibrating means 34 may assist in dislodging reaction products from the electrolytic array 18 that may otherwise become trapped or entrained therewithin or thereupon, thereby reducing the reactive area of the electrolytic array. In one further embodiment, the vibrating means 34 may be an ultrasonic vibration generator, however other suitable vibrating means 34 are known in the art and use thereof should not be considered as departing from the scope of the invention.

[0039] In an embodiment and with further reference to Figure 8, the temperature-resistant cathode 16 may be partially encased in an insulating sleeve 36 extending for a substantial majority of at least a submerged portion thereof. In a further embodiment, the end 16A of the temperature-resistant cathode 16 is not encased by the insulating sleeve 36 and is exposed to contact the water or aqueous solution. In a further embodiment, the insulating sleeve 36 is shaped to inhibit generation of the plasma arc 24 between portions of the temperature-resistant cathode 16 other than the end 16A thereof and the closest plate of the electrolytic array 18, or otherwise to promote generation of the plasma arc 24 from the end 16A of the temperature-resistant cathode 16.

[0040] While the invention has been described with reference to preferred embodiments above, it will be appreciated by those skilled in the art that it is not limited to those embodiments, but may be embodied in many other forms, variations and modifications other than those specifically described. The invention includes all such variation and modifications. The invention also includes all of the steps, features, components and/or devices referred to or indicated in the specification, individually or collectively and any and all combinations or any two or more of the steps or features.

[0041] In this specification, unless otherwise explicitly stated, separate embodiments of the invention are not intended to be regarded as exclusive of one another. Figures are to be understood as illustrating only the features most relevant to the particular embodiment being depicted therein, and the omission of a technical feature in a figure is not to be interpreted as excluding said technical feature from being included or incorporated into the depicted embodiment.

[0042] In this specification, unless the context clearly indicates otherwise, the word “comprising” is not intended to have the exclusive meaning of the word such as “consisting only of”, but rather has the non-exclusive meaning, in the sense of “including at least”. The same applies, with corresponding grammatical changes, to other forms of the word such as “comprise”, etc.

[0043] Other definitions for selected terms used herein may be found within the detailed description of the invention and apply throughout. Unless otherwise defined, all other scientific and technical terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which the invention belongs.

[0044] Any promises made in the present document should be understood to relate to some embodiments of the invention, and are not intended to be promises made about the invention in all embodiments. Where there are promises that are deemed to apply to all embodiments of the invention, the applicant/patentee reserves the right to later delete them from the description and they do not rely on these promises for the acceptance or subsequent grant of a patent in any country.

CLAIMS

1. An electrolysis system comprising:
 - a tank adapted to contain water or an aqueous solution;
 - an electrolytic array comprising electrically conductive plates;
 - a temperature-resistant cathode proximal to, but spaced apart from, a cathodic end of the electrolytic array;
 - a tank anode proximal to, but spaced apart from, an opposing anodic end of the electrolytic array;
 - wherein:
 - the cathodic and anodic ends of the electrolytic array are electrically connected to a negative and positive terminal, respectively, of a first power supply adapted to provide direct-current (DC) power thereto;
 - the temperature-resistant cathode and the tank anode are electrically connected to a negative and positive terminal, respectively, of a second power supply adapted to provide DC power thereto; and
 - at least the temperature-resistant cathode is adapted to generate a plasma arc within the water or aqueous solution between an end thereof and a closest plate of the electrolytic array.
2. The electrolysis system of claim 1, wherein the plates of the electrolytic array are arranged into a plurality of combs, each comb having at least three plates; and
 - each comb further comprises an electrically conductive comb spine extending therebetween and connecting the plates within that particular comb;
 - such that the at least three plates of each comb are arranged along the comb spine to provide a cathodic end plate and anodic end plate, with at least one shield plate therebetween, the cathodic and anodic end plates being located closer to the cathodic and anodic ends of the electrolytic array, respectively.
3. The electrolysis system of claim 2, wherein the electrolytic array is formed by sequentially arranging the plurality of combs between the temperature-

resistant cathode and tank anode such that, for each particular comb in the sequence:

the anodic end plate is at least partially interleaved between the cathodic end plate and the shield plate adjacent thereto of the following comb in the sequence;

the cathodic end plate is at least partially interleaved between the anodic end plate and the shield plate adjacent thereto of the preceding comb in the sequence; and

substantially none of the combs in the sequence are in direct contact with one another.

4. The electrolysis system of claim 2 or 3, wherein, for at least one of the plurality of combs:

at least one of the cathodic end plate, anodic end plate, and at least one shield plate are shaped to increase edge length per unit volume.
5. The electrolysis system of any one of the above claims, wherein at least the second power supply is adapted to provide DC power as dirty DC power.
6. The electrolysis system of any one of the above claims 1 - 5, wherein at least the second power supply is adapted to provide DC power in pulses.
7. The electrolysis system of claim 6, wherein the second power supply provides DC power in pulses with a frequency between 1 – 100 Hz.
8. The electrolysis system of claim 6 or 7, wherein the first power supply is also adapted to provide DC power in pulses.
9. The electrolysis system of claim 8, wherein the first power supply provides DC power in pulses with a frequency between 50 – 50,000 Hz.
10. The electrolysis system of claim 8, wherein there is a phase shift between the pulsed DC power provided by the first and second power supplies.
11. The electrolysis system of claim 10, wherein the phase shift is between approximately 45° and approximately 135°.

12. The electrolysis system of any one of the above claims, wherein the aqueous solution comprises water with a soluble base dissolved therewithin.
13. The electrolysis system of claim 12, wherein the soluble base is a hydroxide.
14. The electrolysis system of claim 12 or 13, wherein a concentration of the soluble base in the aqueous solution is equivalent to potassium hydroxide dissolved in the water at a concentration between 0 – 5% weight per volume (% w/v).
15. The electrolysis system of any one of the above claims, further comprising a vibrating means.
16. The electrolysis system of any one of the above claims, wherein the temperature-resistant cathode is partially encased in an insulating sleeve extending for a substantial majority of at least a submerged portion thereof;
the end of the temperature-resistant cathode is not encased by the insulating sleeve and is exposed to contact the water or aqueous solution;
and
the insulating sleeve is shaped to inhibit generation of the plasma arc between portions of the temperature-resistant cathode other than the end thereof and the closest plate of the electrolytic array.