Dec. 4, 1923. 1,476,284

F. G. CLARK

METHOD OF ELECTROLYSIS

Filed April 7, 1921 2 Sheets-Sheet 1

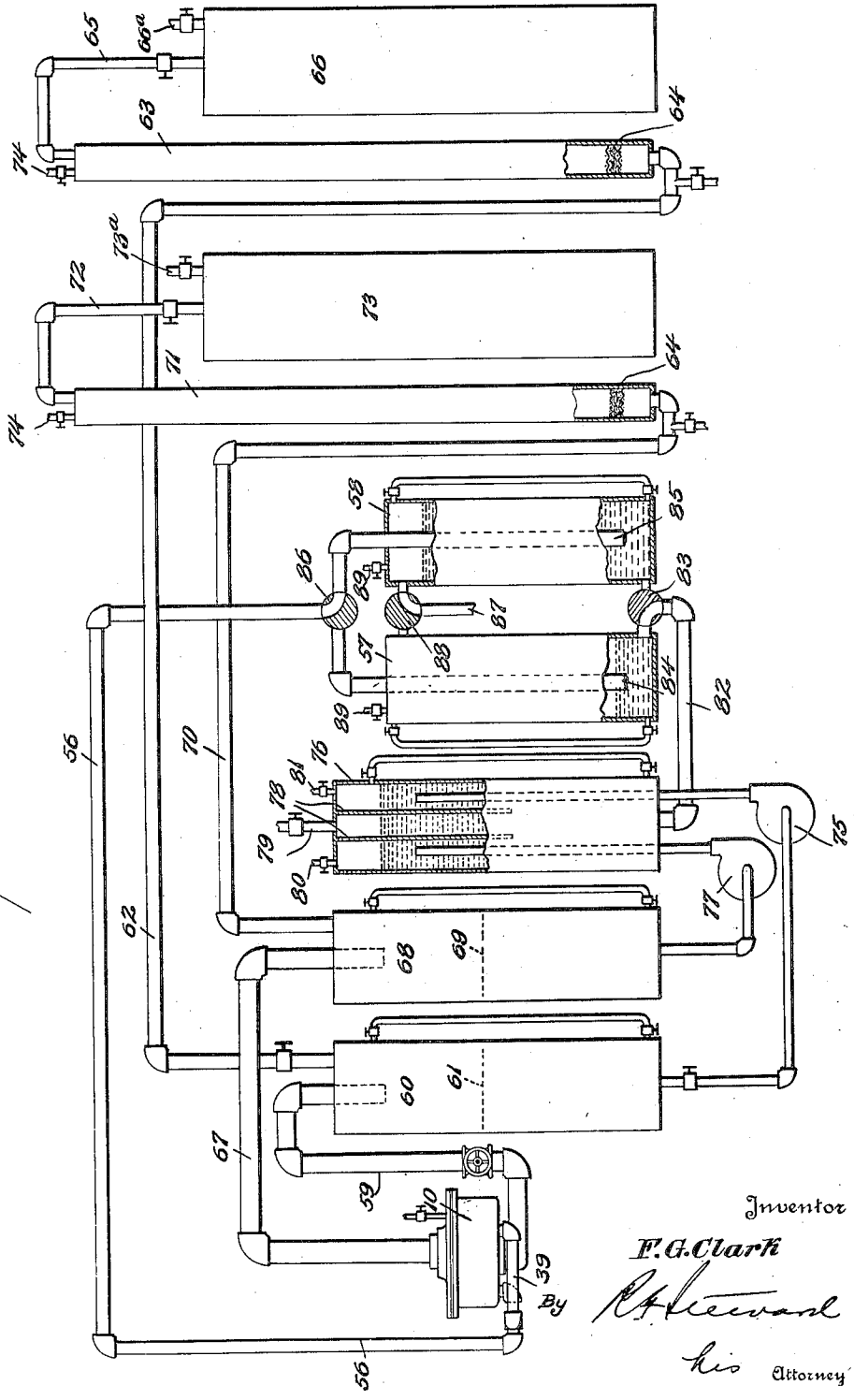

FIG. 1.

Inventor
F. G. Clark
By R. A. Steward
his Attorney

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FIG. 2.

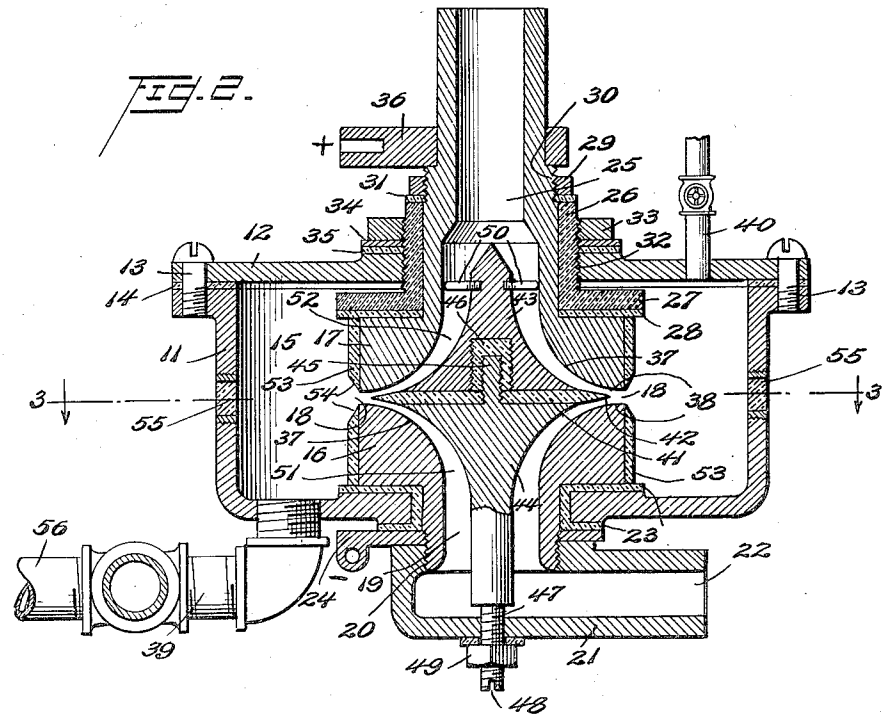
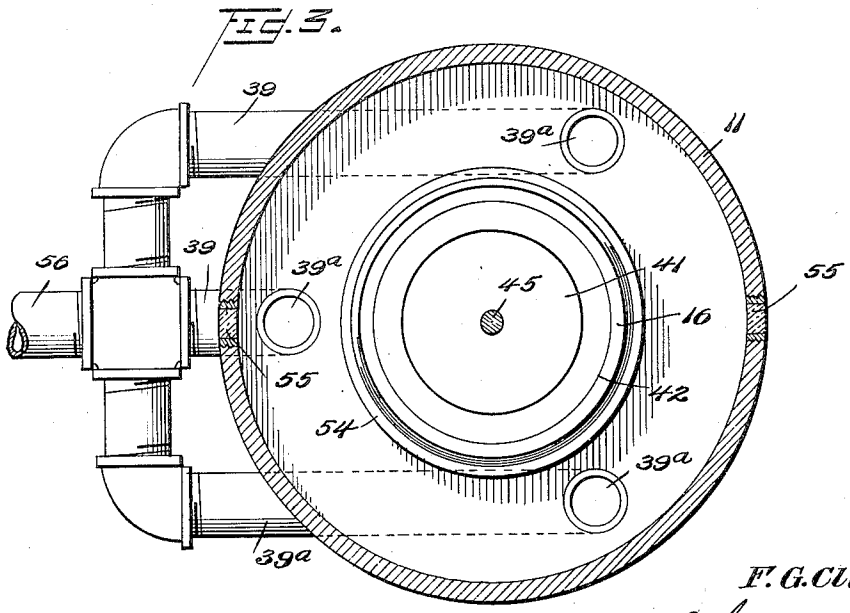


FIG. 3.



Inventor

F. G. Clark

By R. A. Heward

his Attorney.

Patented Dec. 4, 1923. 1,476,284

UNITED STATES PATENT OFFICE.

FARLEY GRANGER CLARK, OF TORONTO, ONTARIO, CANADA.

METHOD OF ELECTROLYSIS.

Application filed April 7, 1921. Serial No. 459,291.

To all whom it may concern:

Be it known that I, FARLEY GRANGER CLARK, a citizen of the United States, residing at Toronto, in the county of York, Province of Ontario, Canada, have invented certain new and useful Improvements in Methods of Electrolysis; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

This invention relates to methods of electrolysis; and the principles involved are of utility in a wide variety of procedures, including electrolysis of saline and other solutions, electrodeposition of metals, and electrolytic operations generally. In its more specific aspects, the invention has to do particularly with the electrolytic generation of oxygen and hydrogen.

The principal objects of the invention are to enable operation at high current densities without sacrificing energy efficiency; to enable separate collection of commercially pure products of electrolysis, where desired, without employment of a pervious separating diaphragm; and in general to simplify and cheapen electrolytic operations, especially the manufacture of oxygen and hydrogen by electrolysis of water.

With the foregoing general objects in view, as well as others that will be apparent from the following detailed description, the invention comprises the various process steps and combinations thereof which will be hereinafter set forth in connection with a desirable practical embodiment of the invention and then more particularly pointed out in the claims.

Broadly considered, the present invention is of general utility and application, and it is therefore not to be understood as limited to the manufacture of only certain specific products. At the present time, however, it is of greatest practical value and importance in the electrolytic generation of oxygen and hydrogen from water, and accordingly this practical application of the process will be especially emphasized and described in detail hereinafter for the sake of a concrete example illustrating the principles upon which the broad invention is based. The employment of the present method in the electrolysis of alkali chlorid solutions for production of caustic alkali and chlorin is instanced as another especially important practical application of the invention in its broader aspects.

Referring more particularly to the specific embodiment of the invention here chosen as an illustrative example, the novel method enables the successful employment, in the electrolytic generation of oxygen and hydrogen, of current densities far in excess of those possible to employ heretofore. It has been substantially universal practice heretofore in the electrolytic production of oxygen and hydrogen by methods proposed by tofore in the electrolytic production of oxysities of less than half an ampere per square inch of projected electrode area, that is, of the cross-sectional area of the current path between electrodes. The present invention renders the employment of high current both possible and commercially feasible By proceeding in the manner hereinafter set forth, it is entirely feasible to employ current densities up to 50 amperes or more per square inch. From my investigations thus far it is apparent that, under properly controlled conditions, even very much higher current densities, say as much as several hundred amperes per square inch, can also be successfully used by proceeding in accordance with the invention. The term high current density as employed in the present application, however, is to be understood in a broad sense, except when otherwise indicated, to include all operative current densities of from say 1 ampere per square inch and upwards.

Since the volume of current flowing through the electrolyte is a measure of the quantity of the resultant electrolytic products, it is evident that, theoretically, the employment of high current densities should greatly increase the output capacity per unit of active electrode surface. But because of numerous complicating factors encountered in actual practice, it has been deemed impossible heretofore by others to obtain these theoretical yields or a reasonable approximation thereof in commercial work. In the first place, it has not been thought possible to operate at high current densities without so reducing the energy efficiency of the operation as to render it wholly impractical from a commercial standpoint. It is to be understood that the expenditure of energy in electrolysis depends directly upon the voltage necessary to be applied to the electrodes to cause elec-

trolyzing current to flow between the electrodes. This voltage at the electrodes is the sum of several constituent parts, including the dissociation voltage of the electrolyte, the resistance of the body of electrolyte between the electrodes, and the so called overvoltage of the electrodes themselves, as well as the variable voltage of polarization due to accumulation of evolved gases on the electrode surfaces and to other factors. The required total voltage may also be influenced by the other considerations also, but the foregoing are of principal importance. In the electrolysis of water for the oxygen and hydrogen, the energy efficiency of the operation is generally referred to an ideal decomposition voltage of 1.69 volts as a 100 per cent basis, this being taken as the decomposition voltage of water at platinized platinum electrodes. On this basis, prior methods of electrolyzing water, which may show current efficiencies of as high as 98 per cent in the production of commercial oxygen and hydrogen, show energy efficiencies varying from 60 to 80 per cent. An energy efficiency of 75 per cent may be taken as a fair average in actual practice. Aside from various other considerations involved, it was invariably found that any attempt to operate at high current densities necessarily meant very greatly increasing the voltage over the electrodes and thus enormously increasing the energy consumption. As a matter of fact, it was not feasible in any event thus to modify prior methods by increasing the applied voltage because of the fundamental disturbances and irregularities in the normal operation of the cells that would ensue. Nor was it understood how the difficulties apparently inseparable from high current density operation could be overcome.

According to the present invention, these difficulties are overcome and operation at high current densities may be effected at an energy efficiency fully as high as, or even higher than, that characterizing commercial practice heretofore at low current densities. This is accomplished in part by shortening and reducing the resistance of the current path between electrodes, and in part by maintaining a circulation of the electrolyte between and across the active electrode surfaces at a sufficiently high velocity to ensure clearing away and entraining the gas particles generated at each electrode surface and quickly leading them away from the vicinity of the opposing electrode. By this means accumulation of gases on the electrode surfaces is largely prevented and the polarizing effects thereof avoided. Most desirably the electrolyte is forced between the cooperating electrode surfaces under pressure at such high velocity that, not only are the electrode surfaces continuously swept free of gas particles as fast as they are generated, but also, when separate collection of the electrolytic products is desired, the tendency for interdiffusion of the anodic and cathodic products of electrolysis may be prevented for a period of time or distance of travel sufficiently long to permit operation without interposing a pervious diaphragm between the cooperating active electrode surfaces. In the best embodiment of the invention, therefore, the employment of a separating diaphragm is dispensed with, and this makes it possible to bring the cooperating electrode surfaces relatively very close together. As a result, the resistance due to length of current path through the electrolyte is greatly reduced and the employment of far greater current densities is made possible without necessitating application of higher operating voltage to the electrodes than has been common practice heretofore. Furthermore, operation at high electrolyte temperatures, which is feasible and desirable in the practice of the invention, still further reduces the resistance of the current path.

When operating without the use of a separating diaphragm interposed between the electrodes, which is the preferred form of the present process, and where it is necessary to collect separately the anodic and cathodic products, as in the manufacture of commercially pure oxygen and hydrogen, it is of course essential to effect division of the body of electrolyte into anolyte and catholyte portions promptly after passage through the electrolyzing zone so that no substantial interdiffusion of the anodic and cathodic products can take place. In a desirable embodiment of the invention, therefore, this division is accomplished by causing the effluent body of electrolyte to impinge upon the suitably thin edge of a separator device immediately after passage through the electrolyzing zone, whereby it is divided or split into anolyte and catholyte portions, from which the respective anodic and cathodic products may subsequently be isolated or otherwise obtained in any well-known or suitable manner. It is apparent that, in order to prevent objectionable interdiffusion of anodic and cathodic products, care must be taken to correlate properly the velocity of electrolyte flow with the distance the electrolyte flows after it enters the electrolyzing zone and before it is divided or split, as described, into anolyte and catholyte portions. In practice, where it is desired separately to collect the electrolytic products, the aforesaid path or distance of travel should be relatively short. In other words, the width or transverse dimension of the electrolyzing zone between the active electrode surfaces should be comparatively small. This end is achieved, and at the same time sufficient output capacity

is attained, by employing electrodes having elongated narrow active surfaces. One suitable form for electrodes of this general character is an annulus of small width or extent. The term annulus is herein used in a broad sense to include not only a circular annulus but also other curved annuli, polygonal annuli, or the like.

It will be observed that the described conditions of operation involve a considerable reduction in cross-sectional area of the current path through the electrolyte, as compared to prior practice, and this factor taken alone would of course tend to increase the resistance to current flow. On the other hand, the length of the current path through the electrolyte is also greatly reduced, and this shortening of the current path may be made to compensate to any necessary extent for the reduction of cross-sectional area or, as it can also be stated, for the great increase in current density. In carrying out the invention for production of oxygen and hydrogen, it is entirely feasible to operate with the active electrode surfaces from $\frac{1}{4}$ to $\frac{1}{10}$ of an inch apart, or even very much closer. In electrolyzing brine on the other hand, the distance between electrodes may be greater.

In order to compel the electrolyte to flow with the requisite velocity between and across the cooperating electrode faces, it is desirable as above pointed out to operate with the electrolyte under pressure. The amount of this pressure may vary considerably, and will necessarily be dependent somewhat upon the distance between the active electrode surfaces, their width, the temperature at which the electrolyte is maintained, and other factors. Where the process is applied to the manufacture of commercial oxygen and hydrogen, the electrolyte may be of any character suitable for that purpose. In practice it is preferred to use a solution of caustic soda or caustic potash in water, the concentration in either case being most desirably such as to give the maximum conductivity. The use of caustic potash is especially desirable because of the fact that the resultant electrolyte has a lower resistance at all temperatures than caustic soda solution.

In order to explain the principles of the invention more fully by means of a specific illustrative example, its application to the manufacture of commercially pure oxygen and hydrogen will now be set forth. While the practice of the novel method or process is not restricted to employment of apparatus of any specific design, one form of apparatus suitable for carrying out the process is illustrated in the accompanying drawings, in which

Fig. 1 represents more or less diagrammatically an assemblage of the complete apparatus in side elevation, parts being shown broken away and in section;

Fig. 2 is a central vertical section through the cell or generator itself, on an enlarged scale; and

Fig. 3 is a horizontal section on the line 3—3 of Fig. 2.

Referring to the drawings, 10 represents generally one form of cell or generator in which the present process may be carried out. This generator comprises a casing consisting of a receptacle 11, having a cover 12 securely fastened thereto by any suitable means such as machine screws 13, a packing gasket 14 being provided to ensure a liquid-tight joint. Within the chamber 15 enclosed by the generator casing, are mounted the electrodes 16 and 17, 16 being the anode and 17 the cathode, in this instance. The electrodes may be of any suitable material having the requisite degree of conductivity and resistance to action of the electrolyte. With an aqueous solution of a caustic alkali, iron or nickel or nickel-plated electrodes are suitable. Or the anode may be made of or plated with nickel, and the cathode of iron. The electrodes are hollow cylindrical members, interiorly bell-shaped and coaxially positioned with the edges of the bells closely adjacent to form an annular gap or slot-like passage for electrolyte flow, as indicated at 18. The general form of the two electrodes may be similar. Thus the hollow interior of the anode contracts inwardly from the slot 18 to form a conduit or pipe 19, which extends through a suitable aperture in the casing bottom and which is externally threaded at 20 for connection to a pipe fitting 21, which latter provides a lateral extension 22 of the conduit 19. By means of this arrangement, the anode 16, extending through the bottom of the chamber 11, and externally shouldered, as shown, may be firmly clamped in position, suitable packing and insulating material 23 being provided to insure a liquid-tight joint and to insulate the anode electrically from the generator casing. A ring terminal 24 surrounds and engages the anode for connecting the same to a suitable current supply. Said terminal may be clamped between the fitting 21 and the insulating gasket 23.

Similarly, the hollow interior of the cathode 17 contracts inwardly to form the pipe or conduit 25 extending through a suitable aperture provided in the cover 12. The pipe or stem portion 25 of the cathode is surrounded by a heavy bushing 26 of insulating material such as hard rubber, for example, which electrically insulates the cathode from the generator casing. Said bushing 26 has a flange 27 bearing against the shouldered exterior of the cathode either directly or through an interposed packing gasket 28. Said bushing is held in position

on the cathode with its flange 27 pressed tightly against the gasket 28, by means of a nut 29 working on the exteriorly threaded portion 30 of pipe 25 and adapted to be turned down solid against the upper edge of the bushing 26 through an interposed packing gasket 31. The assembled bushing and cathode are securely held in position in the cover 12 in any suitable manner, but it is desirable to have the assemblage mounted in such manner as to be adjustable axially toward and away from the opposite electrode. To this end the bushing 26 is externally threaded as indicated at 32 to engage the correspondingly threaded aperture in the cover 12; and the assemblage may be securely held in any adjusted position by means of the lock nut 33, which bears against washer 34 and packing gasket 35, both interposed between said lock nut and the cover 12. A terminal 36 is provided for connecting the cathode to the negative side of the current supply source.

It will be seen that the inner walls of the electrodes curve gently inwardly away from the slot 18 and into parallelism with the generator axis, to form the conduits 19 and 25, which extend in opposite directions from and at right angles to the plane of said slot 18. The inner portion of each electrode in the present construction is in fact a convex curved surface of revolution symmetrical about the central longitudinal axis of the apparatus, and the portion of the surface generatrix indicated at 37 may approximate a circular arc. For a short distance inwardly toward the axis from the extreme outer edges at 18, the adjacent inner surfaces of the electrodes are desirably substantially parallel and plane as indicated at 38, thus providing a narrow annular zone within which the electrode surfaces are substantially parallel. Inwardly beyond this narrow zone, the adjacent electrode surfaces curve away from each other; and consequently, when proper voltage is applied to the electrodes, the current path between the electrodes is confined almost wholly to the comparatively narrow annular zone 38 adjacent their outer edges.

In the ordinary use of the particular apparatus here described, the electrolyte, say a solution of caustic soda or caustic potash in water is supplied to the generator chamber 15 through one or more conduits 39 entering the same through apertures 39ª. The electrolyte is most desirably supplied under pressure and the chamber 15 is maintained full at all times, a valved vent or blow-off pipe 40 being provided to permit escape of air or other gas from the upper part of the chamber when starting. The electrolyte flows at high velocity through the slot 18 between the cooperating electrodes and is subjected in passing across the narrow annular zone 38 to the electrolyzing action of the current. Where separation of the products of electrolysis is essential, as in the manufacture of oxygen and hydrogen, the inflowing sheet or layer of electrolyte should be divided or split into two parts immediately after it has passed through the slot 18 and across the electrolyzing zone. One practical form of means for this purpose is here shown as comprising a separator disc 41, whose thin peripheral edge 42 is presented to the inflowing body of electrolyte at a locality closely adjacent the inner edge of the electrolyzing zone 38 and approximately midway between the adjacent electrode surfaces. This separator member may be supported in position in any suitable manner. Most desirably it should be so supported that it can be adjusted vertically for attainment of the optimum position to effect proper separation of the inflowing electrolyte into anolyte and catholyte portions. Owing to the fact that the volume of hydrogen generated is twice that of the oxygen the proper position of the separator disk edge may be somewhat nearer the anode in some cases. In the present instance the separator disc is held between an upper member 43 and lower member 44 to be described in greater detail presently. The lower member 44 is provided with a threaded stem 45 which extends through a central aperture in the disc 41 for threaded connection to the upper member 43. Where the members 43 and 44 are of metal, as in the present instance, it is desirable to electrically insulate them from each other; and to this end the disc 41 is here shown as made of insulating material, while the threaded connection between member 43 and the stem 45 is effected by means of an internally and externally threaded insulating nut or bushing 46. The complete separator structure 41, 43, 44, is supported with its central vertical axis coincident with the central vertical axis of the cooperating electrodes. In this instance, the lower separator member 44 has a threaded stem 47 extending through the lower wall of the fitting 21; and by means of a suitable tool engaging the kerf 48 at the end of the stem, the position of the entire separator structure may be adjusted vertically as desired and locked in adjusted position by means of a lock nut 49. The upper member 43 is desirably provided with radially extending pins 50 to accurately center the upper portion of the separator structure in the central axis of the conduit 25. The best position of the separator edge 42 with respect to the cooperating electrode surfaces, for effecting separation of anolyte from catholyte depends upon various factors such as velocity of electrolyte flow, width of gap transverse to electrolyte flow, or the like; but may be determined in any given instance from an

examination of the hydrogen and oxygen recovered.

The outer surfaces of the members 43 and 44 are concave surfaces of revolution, the generatrix of each being of such form that each surface merges smoothly into the surface of the sharp edged separator disc 41 and diverges slightly from the adjacent curved surface 37 of the cooperating electrode member as the separator member surface curves inwardly toward the central axis. By virtue of this arrangement, the annular passages 51 and 52 thus formed for anolyte and catholyte, respectively, flare or expand smoothly in a direction inwardly from the electrolyzing zone 38, whereby the velocity of the electrolyte is considerably reduced below the velocity maintained in the electrolyzing zone. This, and the subsequent further enlargement of the anolyte and catholyte conduits, is advantageous in that it brings about a relatively quiescent condition of the anolyte and catholyte which favors separation of the oxygen and hydrogen, respectively, therefrom.

As here shown, the exterior surfaces of the electrodes are covered with insulating material 53, which is most desirably beveled or otherwise formed at the edges of the electrodes to provide a converging approach 54 for the electrolyte to the slot 18. The side walls of the generator casing may also be provided with observation windows 55 whereby the conditions within the generator may be observed.

The cell or generator 10, above described, is not claimed herein but is the subject matter of a copending application for patent of Farley G. Clark and James N. Smith, entitled Electrolytic apparatus, filed on even date herewith and numbered serially 459,292.

In employing the complete system illustrated in Fig. 1, for the manufacture of commercially pure oxygen and hydrogen, in accordance with the invention, caustic soda or caustic potash electrolyte is supplied under pressure to the generator 10 through valved supply pipe 56 from one or the other of the pressure supply tanks 57, 58. After passing at high velocity between the generator electrodes and after having been divided into anolyte and catholyte portions, all as hereinabove described, the anolyte passes out of the generator casing through conduit 59, and is discharged into the upper portion of the anolyte and oxygen separating tank 60, above the liquid level 61 therein. Separated oxygen collecting in the upper part of tank 60 passes off through pipe 62 into the bottom of a washer or scrubber 63 which may contain water and which may be provided in its lower portion with a foraminous partition or screen device 64 by means of which the gas is divided into fine bubbles and is thus thoroughly exposed to the washing liquid. From the scrubber, the oxygen passes through conduit 65 to a holder 66 of any suitable type from which it may be led at a controlled rate through valved outlet 66[a].

In a similar manner, catholyte and hydrogen leaving the generator through outlet 25 pass through conduit 67 and are discharged into the upper part of catholyte and hydrogen separating tank 68 above the liquid level 69 therein, the separated hydrogen being conducted through pipe 70 into the lower part of washer or scrubber 71, which may be similar in all essential respects to the washer or scrubber 63. Purified hydrogen passes from the scrubber through pipe 72 into a holder 73, which has a valved outlet 73[a]. Each of the scrubbers 63 and 71 is provided with a relief vent 74 for use whenever required.

For the sake of clearness in illustration, the off-takes 59 and 67 leading from the generator are here shown as extending upward to different levels. In practice, however, they would extend to the same level, where it is desired to maintain the effluent anolyte and catholyte under the same pressure.

Separated anolyte is drawn from the lower part of the tank 60 by means of a pump 75 and is forced into the upper part of an electrolyte supply tank 76; while the pump 77 similarly draws catholyte from the lower part of tank 68 and discharges the same into the upper part of tank 76. A pair of spaced baffle walls 78 extend from the top of the tank 76 for some distance toward the bottom thereof in such manner as to separate the anolyte and catholyte discharged into the upper part of the tank but to permit the same to commingle below the lower edges of said baffle walls. Make-up water to compensate for the water decomposed in the electrolyzer may be introduced through valved pipe 79 into the space between the baffle walls. Valve pipes 80 and 81 may be employed to separately discharge or lead away hydrogen and oxygen, respectively, that may collect in the upper part of the tank 76 on opposite sides of the pair of baffle walls aforesaid. Electrolyte from tank 76 is continuously forced under pressure through pipe 56 back to the generator chamber in any suitable manner. In the arrangement here illustrated, this is accomplished by means of pressure tanks 57 and 58 which act in alternation to receive electrolyte from tank 76 through pipe 82 and three-way valve 83, and to discharge the same by way of pipe 84 or pipe 85, as the case may be, through three-way valve 86 into said pipe 56. In the present instance, compressed air supplied from any suitable source through pipe 87 and three-way valve

88 may be the pressure medium. In the position of the parts illustrated in Fig. 1, electrolyte is being forced from tank 58 into pipe 56, while tank 57 is receiving electrolyte from tank 76. By the time tank 58 is empty, tank 57 is filled. The valves 83, 86 and 88 are then actuated to discharge tank 57 and fill tank 58. Each of tanks 57 and 58 is provided with a vent 89 which is open when the tank is being filled and closed when it is discharging. The arrangement may include means (not shown) acting automatically to reverse the valves 83, 86, 88 in time to prevent uncovering the lower end of pipe 84 or 85, as the case may be.

The pressure on the electrolyte supplied to the generator, and consequently the velocity of the electrolyte flow between the active electrode surfaces, may be varied as desired by varying the pressure of the air used to expel electrolyte from the tanks 57, 58, which of course function continuously in alternation while the system is in operation. Velocity of electrolyte flow through the electrolyzing zone can also be varied and regulated by adjustment of the cathode toward or away from the anode, which adjustability also enables compensation for gradual wear of the electrode surfaces by erosion or chemical attack of the electrolyte. Not only does the high velocity of electrolyte flow between the electrodes enable separate collection of the electrolytic products without using a diaphragm, but it also continually clears the active electrode surfaces of products of corrosion or the like and maintains the surfaces always in active condition. The rate at which the pumps 75 and 77 are run to withdraw anolyte and catholyte from tanks 60 and 68, respectively, can of course be varied in accordance with the rate at which anolyte and catholyte is discharged into said tanks.

In a typical instance, the active electrode surfaces may be one-tenth of an inch apart at the gap or slit 18, and the electrolyte may be supplied to the generator chamber 15 at a pressure of say 30 pounds per square inch, these figures being understood as merely illustrative of one mode of operation. Under such conditions, satisfactory operation may be had at a current density of 50 amperes per square inch or even higher, this current density being figured on a basis of the total current flowing between the annular electrode surfaces 38, the width of the annulus in the direction of electrolyte flow being defined approximately by the extreme outer edges of the electrodes on the one hand and the sharp edge 42 of the separator disc 41, on the inner side. It is advantageous to operate with the temperature of the electrolyte only slightly lower than that at which ebullition occurs at the pressure employed. Thus, when operating under 30 pounds pressure, and using a 30 per cent solution of caustic potash as the electrolyte, a temperature of 125° C. is suitable. This is of course somewhat above the boiling point of the electrolyte at atmospheric pressure. The heat developed by the electrolysis will suffice to maintain such temperature, especially if the heat generated be conserved by insulating the generator and other parts of the apparatus by means of suitable heat covering. Any heat generated in excess of what is required to maintain the electrolyte in the cell at the proper operating temperature can be absorbed at a point outside the cell and utilized in any suitable way, as in distilling make-up water, for example. Control of the temperature in the cell can be effected by varying the velocity of electrolyte flow between and across the electrodes. In any event, the rate of flow must be high enough to prevent arcing across between the active electrode surfaces. In general, the principal factor determining the proper rate of flow is the distance between the active electrode surfaces. In operating at 500 amperes per square inch, with the electrode surfaces as little as 0.01 inch apart, for example, the velocity of electrolyte flow, and consequently the impelling pressure head on the electrolyte must be greater than when the electrodes are a tenth of an inch apart. Generally speaking it is desirable in any case that there shall be a substantial difference in pressure on opposite sides of the electrolyzing zone, say at least one pound or more, in order to ensure sufficiently rapid flow of electrolyte through said zone. This difference in pressure being of principal importance, it is evident that the employment of sub-atmospheric pressure is not precluded; and reference herein to employment of an impelling pressure head is therefore to be given a correspondingly broad interpretation.

It will be noted that by operating with the active electrode surfaces in horizontal planes, and with the cathode uppermost, advantage is taken of the extreme lightness and buoyancy of hydrogen to assist in removing it from the vicinity of the anode and thereby further to guard against diffusion of hydrogen into the oxygen. This or any other arrangement of the electrodes that utilizes the greater buoyancy of the hydrogen for the purpose described, thus facilitates production of especially pure oxygen.

While the present method is especially adapted to operation without a separating diaphragm interposed between the active electrode surfaces, the invention in its broader aspects does not exclude employment of separating diaphragms of metal, asbestos, or other suitable material, in cases where this may be desirable. However, the use of a diaphragm is ordinarily less advantageous because of the increase in resist-

ance necessarily occasioned thereby. Neither is it to be understood that the process, considered broadly, necessarily involves recovery of the anodic and cathodic products separately. Thus, the advantages of the invention can also be realized in part in electrolyzing water for production of detonating gas, in the manufacture of bleaching liquor by electrolysis of brine, or in other analogous procedures where commingling of the products of electrolysis is not disadvantageous. While the application of superatmospheric pressure of the electrolyte has been mentioned for the purpose of producing the effective impelling head required for attaining the proper velocity of flow, such head may in some cases be produced wholly or in part by suitable application of suction to the discharge side of the generator or cell.

What I claim is:

1. The electrolytic process which comprises flowing a stream of electrolyte across an unobstructed electrolyzing zone at a velocity great enough to prevent substantial interdiffusion of the resultant anodic and cathodic products while in said zone, and then dividing said stream into separate portions comprising anodic and cathodic products, respectively.

2. The electrolytic process of producing mobile anodic and cathodic products which comprises passing an electrolyzing current directly through a relatively thin undivided layer of an electrolyte flowing under an impelling pressure head.

3. The electrolytic process which comprises passing an electrolyzing current directly through a relatively thin undivided layer of an electrolyte flowing under pressure exceeding one atmosphere.

4. The electrolytic process which comprises electrolyzing a rapidly flowing stream of electrolyte at relatively high current density, and separately conducting away resultant anodic and cathodic portions of said stream before substantial interdiffusion occurs.

5. The electrolytic process of producing mobile anodic and cathodic products which comprises forcing an electrolyte to flow rapidly across a narrow electrolyzing zone and subjecting it while in said zone to an electrolyzing current.

6. The electrolytic process which comprises forcing an electrolyte to flow at substantial velocity across a narrow electrolyzing zone and subjecting it while in said zone to an electrolyzing current, and separately conducting away resultant anolyte and catholyte portions of said electrolyte.

7. The electrolytic process of producing mobile anodic and cathodic products which comprises forcing a thin layer of electrolyte to pass at high velocity between closely adjacent active electrode surfaces furnishing electrolyzing current at high density, and collecting the products of electrolysis.

8. The electrolytic process which comprises forcing an electrolyte to flow at high velocity across the closely adjacent active surfaces of cooperating electrodes which are relatively narrow in the direction of electrolyte flow, while passing current at high density between said electrodes.

9. The electrolytic process which comprises maintaining a forced flow of an undivided body of an electrolyte between suitably energized electrodes in a direction generally transverse to that of current flow and at a sufficiently high velocity to prevent substantial inter-mixture of resultant anodic and cathodic products, and separating such products before substantial inter-mixture occurs.

10. The electrolytic process which comprises forcing an electrolyte under pressure to flow rapidly through a narrow annular passage formed between closely adjacent annular faces of cooperating energized electrodes, and preventing substantial intermixture of anodic and cathodic products in the electrolyte that has passed between said electrodes.

11. The electrolytic process which comprises passing a body of electrolyte at high velocity between and across relatively narrow active electrode surfaces directly exposed to each other, and then dividing said body into separate portions containing resultant anodic and cathodic products, respectively.

12. The electrolytic process which comprises passing a body of electrolyte at high velocity between and across relatively narrow and closely adjacent active electrode surfaces directly exposed to each other, and then dividing said body into separate portions containing resultant anodic and cathodic products, respectively.

13. The electrolytic process which comprises subjecting a swiftly flowing body of electrolyte to an electrolyzing current at a density exceeding 50 amperes per square inch of projected active electrode area.

14. The process of electrolyzing water which comprises passing a high density water-electrolyzing current through an undivided layeriform aqueous body flowing rapidly.

15. The process of electrolyzing water which comprises directing a relatively thin body of an aqueous electrolyte across an unobstructed electrolyzing zone in which a water-electrolyzing current is passed through said body of electrolyte.

16. The process of electrolyzing water which comprises subjecting a flowing body of a suitable aqueous electrolyte to the action of electrolyzing current at a density of at least from 5 to 10 amperes per square inch of projected active electrode area.

17. The process of electrolyzing water which comprises subjecting a flowing body of a suitable aqueous electrolyte to the action of electrolyzing current at a density of at least 50 amperes per square inch of projected active electrode area.

18. The process of electrolyzing water which comprises passing a relatively high density electrolyzing current through a relatively thin body of aqueous electrolyte flowing under an impelling pressure.

19. The process of electrolyzing water which comprises passing an electrolyzing current through a relatively thin body of aqueous electrolyte flowing under an impelling pressure and maintained at a temperature above its normal boiling point.

20. The process of producing oxygen and hydrogen electrolytically which comprises passing current between cooperating electrodes through an aqueous electrolyte, while compelling said electrolyte by application of pressure to travel between said electrodes in a direction generally transverse to that of current flow and at a velocity sufficiently high to sweep the respective evolved gases from the active electrode surfaces without substantial intermixture, and separating the electrolyte after passage between said electrodes into portions carrying hydrogen and oxygen, respectively.

21. The process of producing oxygen and hydrogen electrolytically which comprises maintaining a pressure-induced flow of a suitable aqueous electrolyte between and across the closely adjacent active faces of cooperating suitably energized electrodes at a velocity great enough to prevent substantial intermixture of the generated gases, and directing the resultant gas-laden anolyte and catholyte into separate paths for collection of oxygen and hydrogen, respectively.

22. The process of producing oxygen and hydrogen electrolytically which comprises forcing a suitable aqueous electrolyte under pressure through a constricted passage, subjecting said electrolyte while in said passage to the action of current at proper electrolyzing voltage, the velocity of electrolyte flow being great enough to prevent substantial inter-diffusion of the generated gases while in said passage, and directing the resultant gas-laden anolyte and catholyte into separate paths for collection of oxygen and hydrogen, respectively.

23. The electrolytic process of generating gases, especially oxygen and hydrogen, which comprises flowing an undivided body of electrolyte rapidly between and across relatively narrow active electrode surfaces, dividing the still rapidly flowing effluent body into anolyte and catholyte portions, then reducing the velocity of flow and effecting separation of gases from said portions.

24. The electrolytic process of producing mobile anodic and cathodic products, characterized by the employment of relatively high current densities and rapid flow of electrolyte in a thin layer through an electrolytic zone of comparatively small width, substantially as described and for the purposes set forth.

25. The electrolytic process which comprises providing a flowing stream of an electrolyte, reducing that stream in one portion of its path of travel by interposition of cooperating electrodes having faces adapted to form said stream into a thin undivided layer of the electrolyte to reduce the resistance of the current path through the electrolyte to a degree permitting high current density and passing current at high density between said electrodes.

In testimony whereof I hereunto affix my signature.

FARLEY GRANGER CLARK.