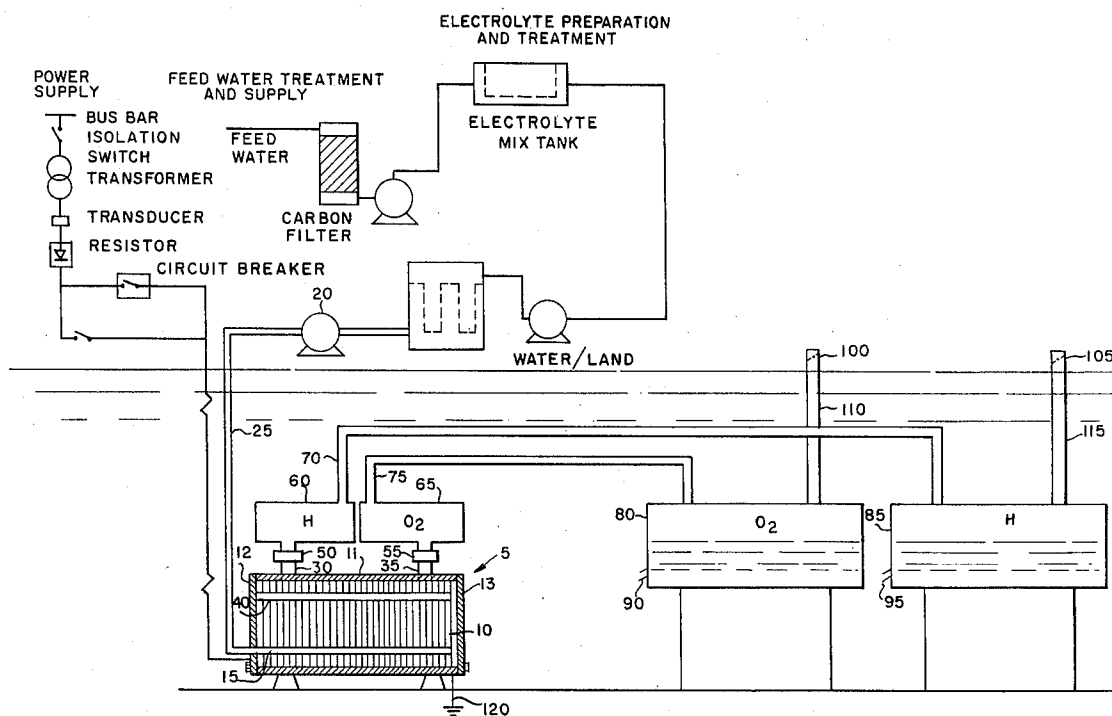
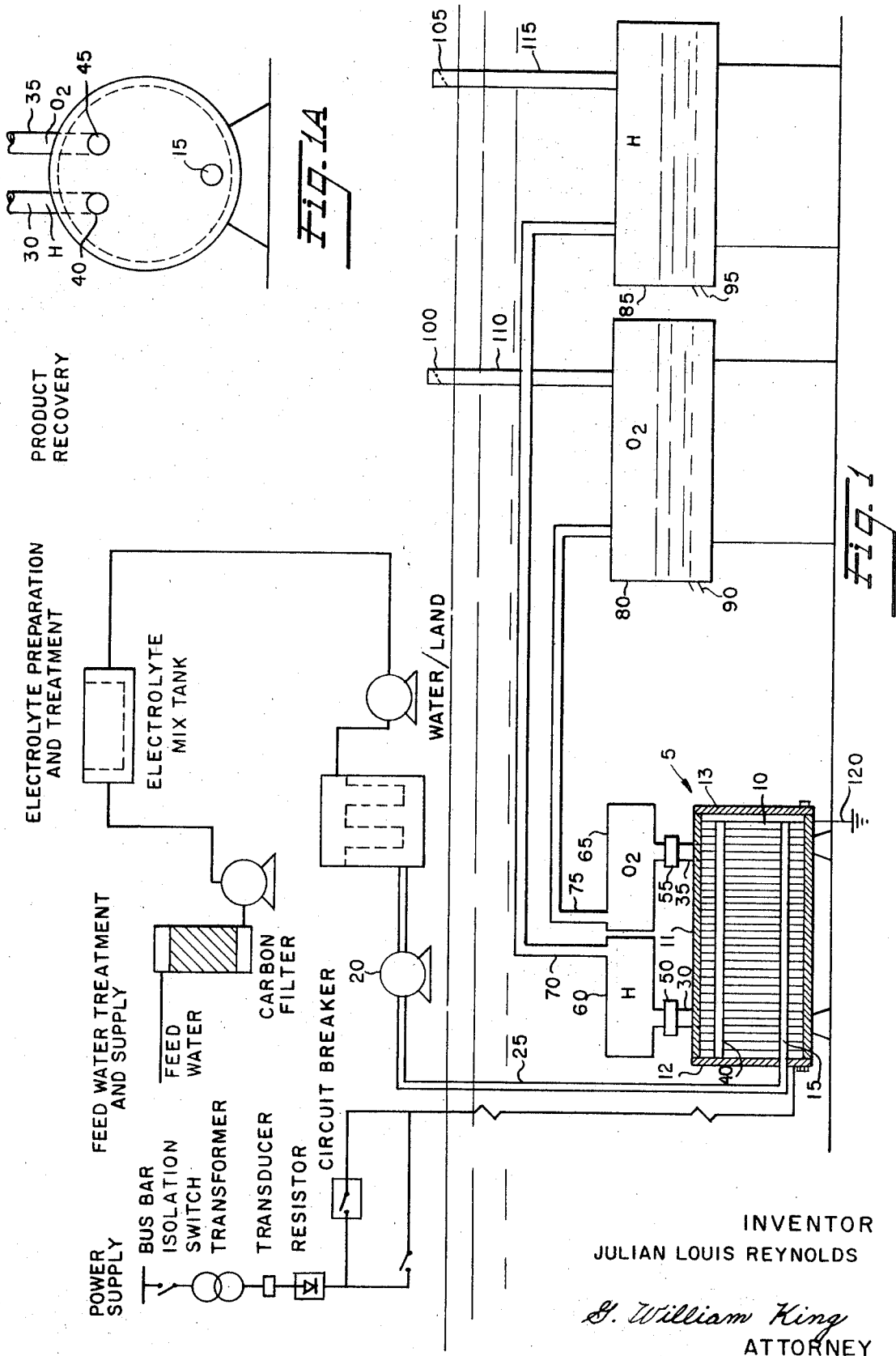


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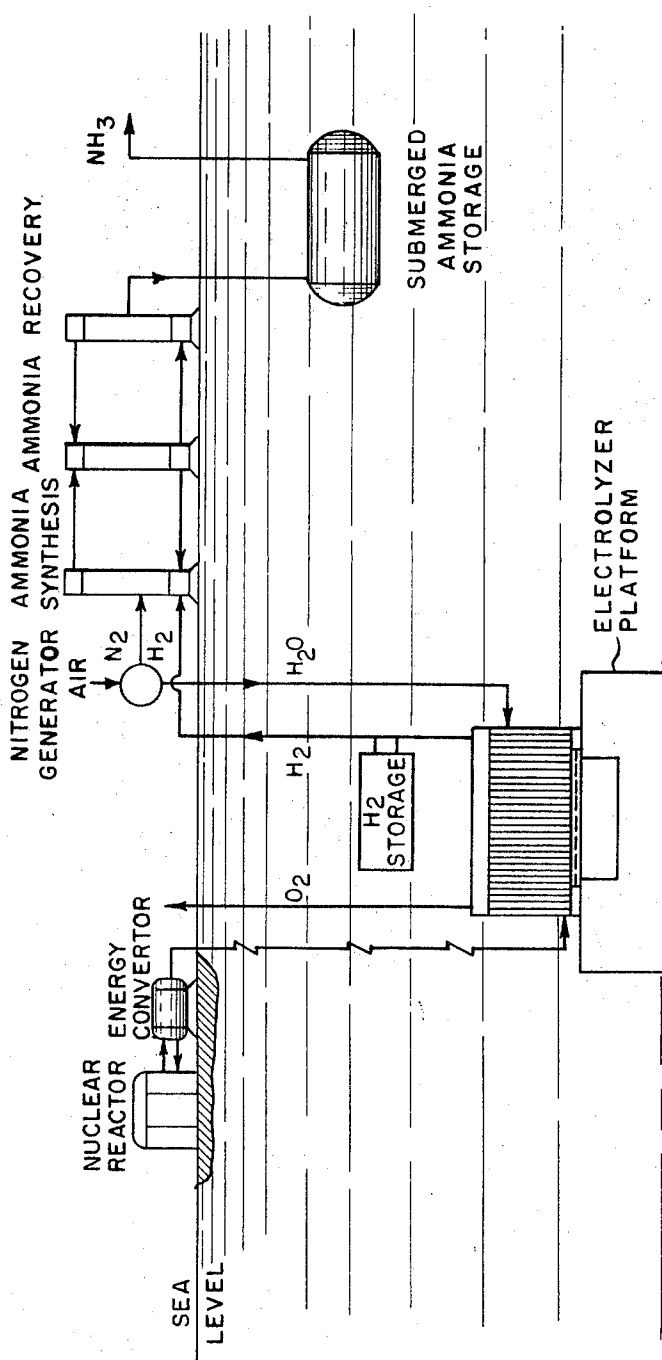


Fig. 2

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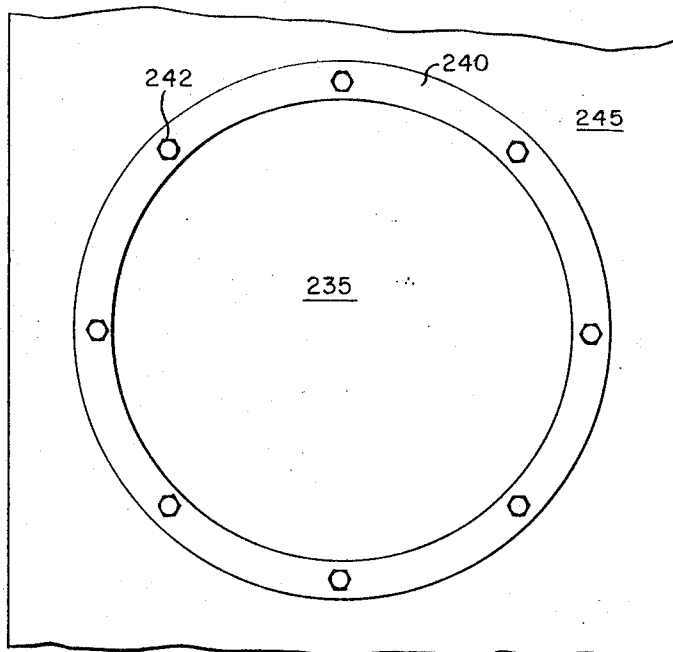
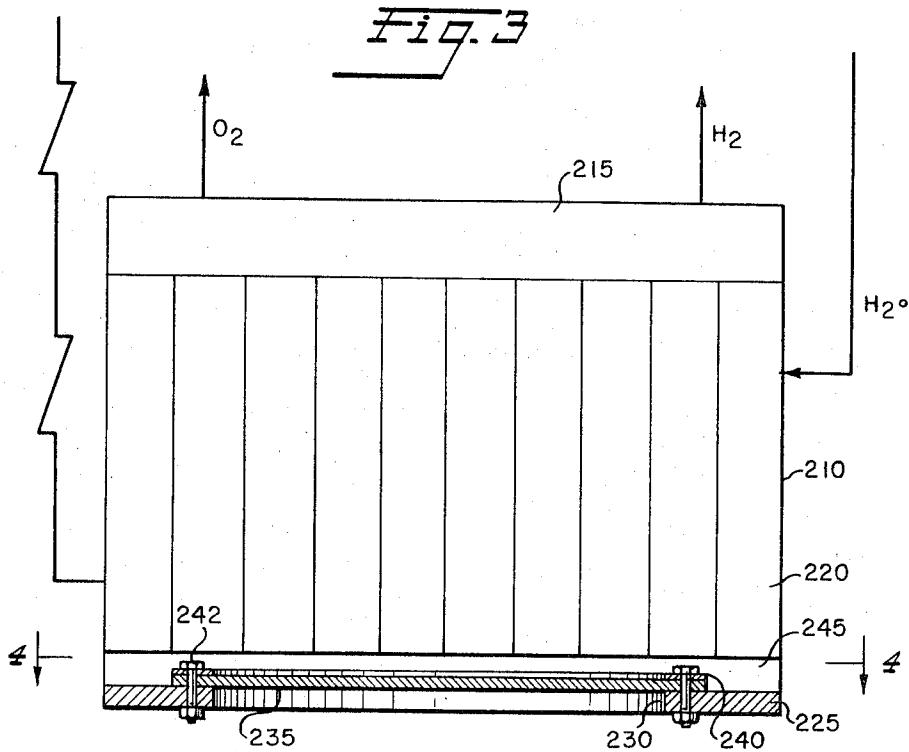
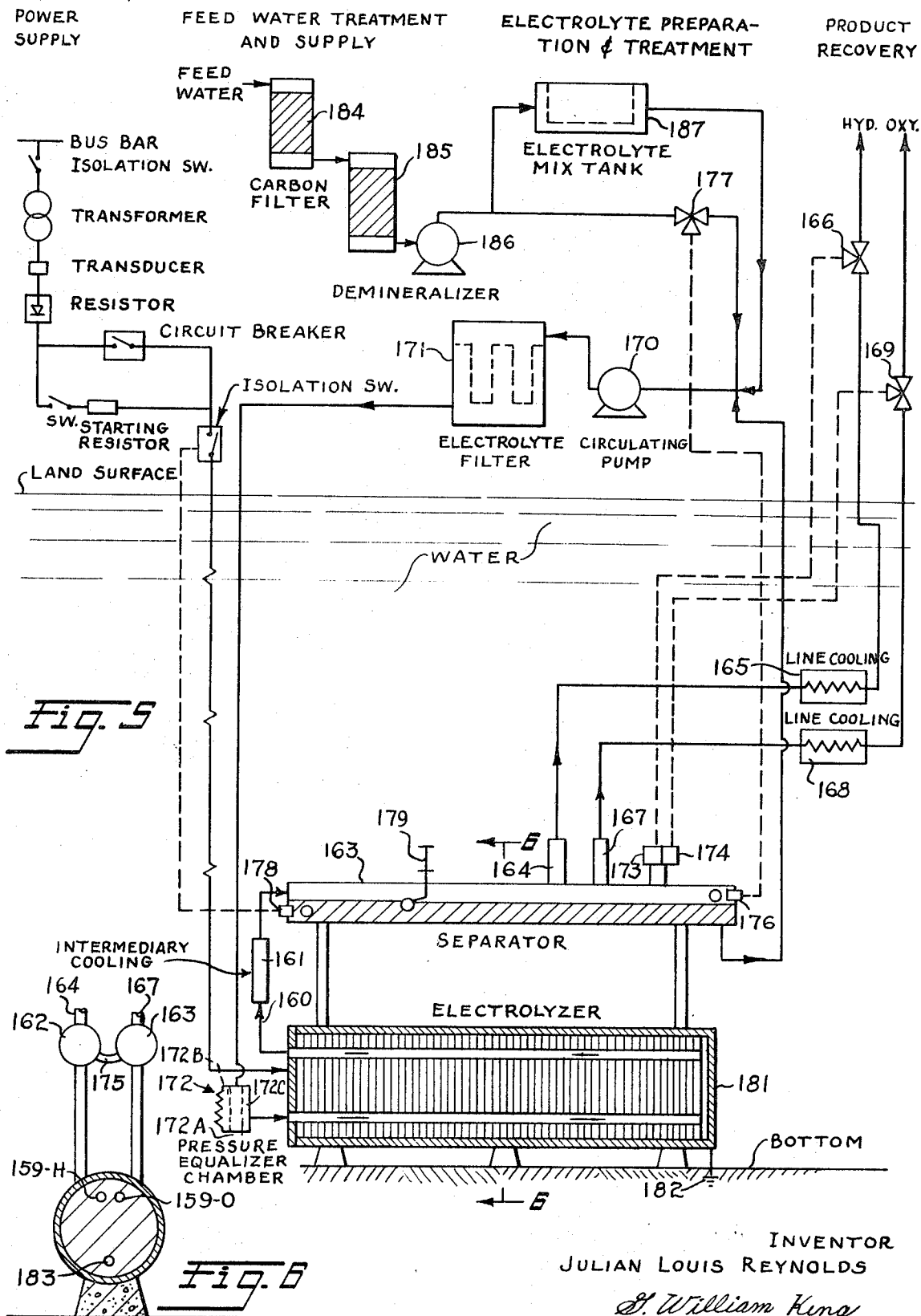


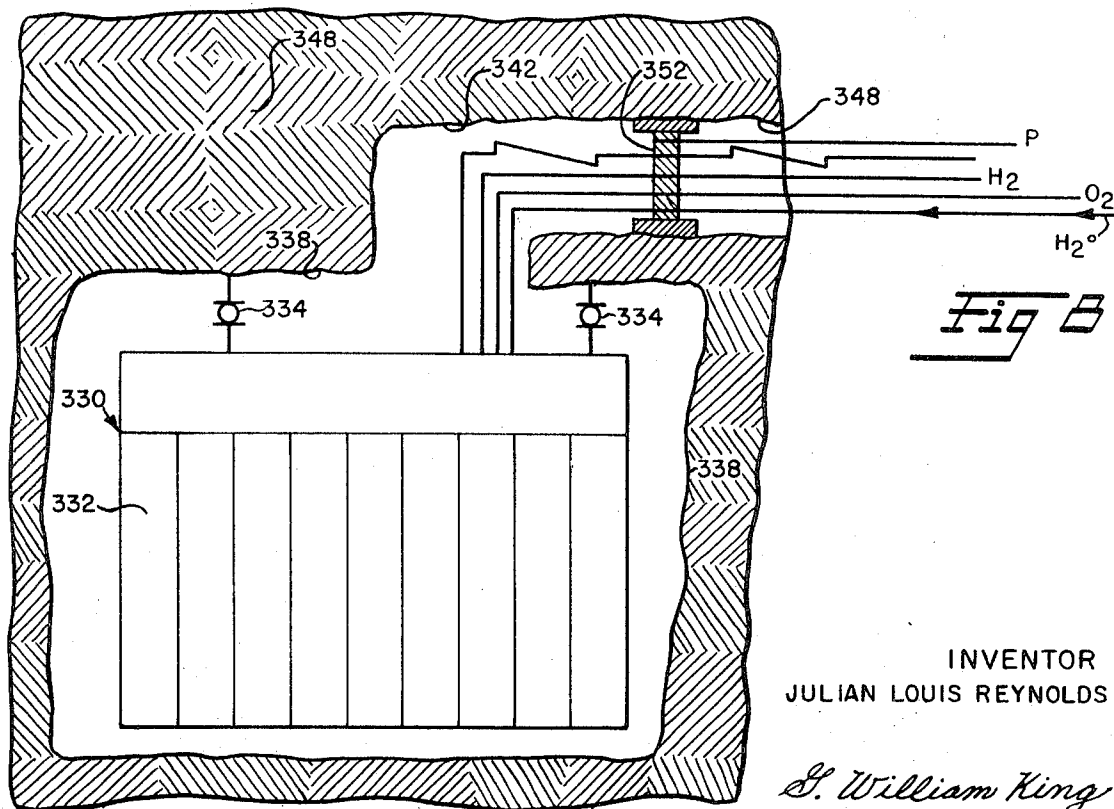
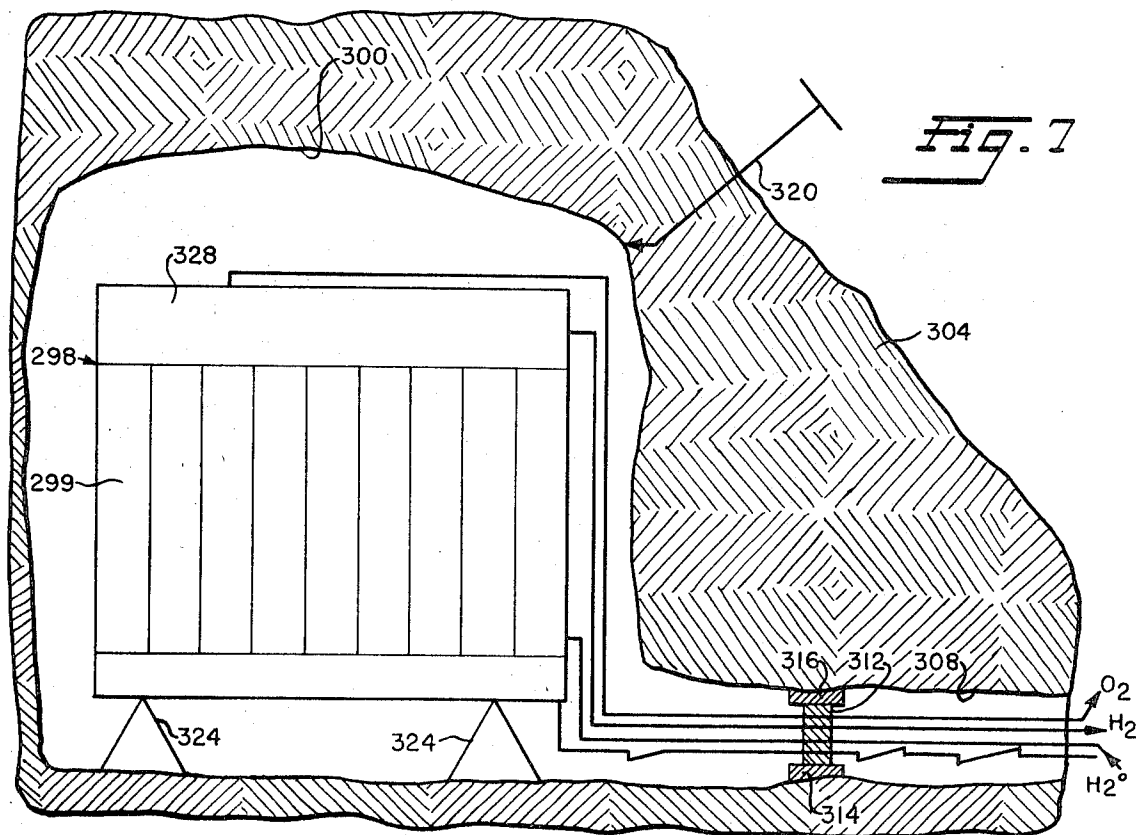
Fig. 4

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METHOD OF OPERATING AN ELECTROLYSIS CELL FOR THE PRODUCTION OF GASES UNDER HYDROSTATIC PRESSURE

This application is a continuation-in-part of application Ser. No. 503,693 filed Oct. 23, 1965 now abandoned.

This invention relates to novel processes for producing chemical compounds and compositions, and to novel apparatus therefore. More particularly this invention relates to novel processes for producing chemical substances in a pressurized environment, and apparatus therefore.

The basic principles of this invention are particularly useful in electrolytic processes carried out in pressurized environments, and are hereinafter described in connection with electrolytic production of hydrogen and oxygen, although as will become apparent from the following, these same basic principles may be utilized broadly in many chemical and electrochemical processes, particularly those favored by high pressures, and insofar as they are applicable in such other processes, are intended to be embraced by, and included in, this invention.

There have been several previously known endeavors related to pressure electrolysis wherein internal pressure environments have been created artificially in expensive, heavy metal walled pressure vessels operating in plants where substantially ambient conditions existed. One aspect of this invention, broadly stated, is that it differs from such endeavors by making use of geological features of the earth's surface and subsurface wherein high pressure conditions exist and may be utilized as an environment for carrying out chemical or electrochemical processes.

Production of hydrogen and oxygen by electrolysis in a pressurized containment vessel has several advantages over prior methods, and has been carried out on a commercial scale for some time. For example, many of these plants use electrolyzers containing bipolar cells which must undesirably be relatively small, usually approximately one-fifth the size of the more conventional monopolar cells and which produce hydrogen at pressures in the order of 30-200 atmospheres gauge. Nevertheless, certain advantages may be derived by operating under pressure, for example, by operating in a pressurized containment vessel, the cell will require lower voltage (the voltage decreasing as pressure increases), enable the electrolyzer to carry higher amperage thereby reducing voltage of the cells still further since they will be able to tolerate higher temperatures, operate with less specific power consumption than the normal 0.130 to 0.145 kwh/scf level of atmospheric pressure electrolyzers, utilize energy more efficiently and require less cooling than atmospheric pressure electrolyzers, and even save mechanical compression costs by delivering the produced gases at a pressure substantially equal to the electrolyzer operating pressure. The latter may be of particular advantage where it is desired to deliver a gas under pressure into another chemical process, for example, as is desirable in synthetic production of ammonia to effect savings in compression and large storage vessels.

While the foregoing advantages may be achieved by pressure electrolysis, nevertheless there are many problems related to the pressurization which produce economic and operating difficulties. Of prime importance is the maintenance of a completely sealed operating system. Because of the conditions under which an electrolytic cell works, even a minute leak to atmosphere of one of the gases will cause differences in pressure between the anode and cathode spaces, possibly permitting the gases to intermix and create a dangerous situation. Thus the containment vessel must be constructed from suitable high quality materials with precision to prevent leakage, and yet permit the produced gases to be drawn off after dissociation at the proper rates to maintain a balanced system. Considering the foregoing, high pressure electrolyzers, as compared to atmospheric electrolyzers, are presently required to have thick, expensive containment vessel walls and to use relatively small electrode surfaces.

Briefly, the present invention overcomes the above-mentioned, and other, disadvantages of high pressure electrolytic units, and in addition, provides several advantages. In accordance with the present invention, a process is provided in which electrolytic units are subjected not only to internal pressure but also to the super-atmospheric pressure of an external environmental medium in which the cell containment vessel resides during operation. Among the advantages that may be achieved is an economical benefit over previously known electrolyzers, in both construction and operation. Moreover, in a medium such as water, the produced gases are at substantially the same pressure as the medium and do not tend to leak out, but even if they did, a dangerous condition would not be immediately created. Thus, in addition to operating economies, insurance and equipment costs may be saved.

In particular, the preferred embodiment of the present invention has, as its basic principle, maintaining the internal and external containment vessel pressures substantially equal by, for example, placing a containment vessel in a fluid medium (such as water) having a pressure head at the depth at which the vessel resides, approximately equal to the desired internal operating pressure of the electrolytic unit, or by utilizing a novel containment vessel which will permit the fluid pressure head to establish substantially the same pressure inside the vessel as outside, whereby the stresses normally created in the containment vessel by the operating internal pressure will be substantially offset by the external pressure of the fluid medium. The external pressure medium is not restricted to a fluid medium, but may include a gas medium or in some instances a solid medium or various combinations thereof. As a result of the externally applied pressure, the containment vessel may be constructed of thin, relatively inexpensive materials, large electrode space may be used, and in general all of the advantages of atmospheric pressure units may be achieved while at the same time the unit may be operated under pressure to also achieve all of the advantages of the pressurized unit.

The electrolytic cell construction useful in a pressurized containment vessel in accordance with this invention may be of any suitable known construction, and is not a critical factor of the invention. Thus it is possible to utilize the principles of this invention with electrolytic cells having separate electrodes, or as unit cells containing two anodes and one cathode or vice versa, or as multiple cells, diaphragm cells, bell-jar cells, etc.

Accordingly, it is a primary object of the present invention to provide a novel process, and novel apparatus therefor, for carrying out chemical and electrochemical processes under pressure, and in particular, to provide the same by utilizing pressure of an external medium to offset the disadvantages of internal pressures in containment vessels, normally encountered in chemical and electro-chemical processes.

Another object of the present invention is to provide a processing system in which a containment vessel is placed in a medium, the pressure head of which is utilized to raise the containment vessel internal pressure as well as the external pressure or only to offset internal pressure produced in the vessel by previously known pressurizing methods.

Still other objects of super-atmospheric present invention are to provide: non-existent

A novel process for superatmospheric pressure electrolysis of water to produce hydrogen and oxygen in a containment vessel having a low or nonexistent pressure differential between its interior and exterior;

A novel process of creating super-atmospheric pressure conditions in an electrolyzer containment vessel;

Novel apparatus comprising, in general, containment vessels adapted to be located in or under an external medium and establish the pressure of the internal medium without permitting said external medium to intermix with the internal medium which constitute the contents of the vessels;

Processes and systems supplying the aforesaid containment vessels with raw materials, and removing the process products under pressure;

Processes for producing chemicals and chemical compositions under pressure by chemical and electrochemical means utilizing reaction vessels pressurized by an external medium;

Apparatus for removing and storing the products produced under pressure in storage vessel similarly situated in a super-atmospheric high pressure medium or otherwise adapted to maintain the products under pressure until release for transmission or consumption;

Processes and apparatus for electrolysis of water under high pressure in an external medium such as water, the pressure head of which at the containment vessel depth establishes a pressure therein approximately equal to that of the external medium.

Various other objects, advantages and features of the invention will become apparent to those skilled in this art from the appended claims and following description of the best mode of carrying out the present invention, and modifications thereof, taken in connection with the accompanying drawings wherein;

FIG. 1 is a schematic drawing illustrating an electrolyzer positioned on the bottom of a body of water with flow sheet indications of the system for operating the same. FIG. 1-A is an end view of the electrolyzer shown in FIG. 1.

FIG. 2 is a schematic drawing of an electrolysis plant in accordance with the present invention, shown in conjunction with a plant for producing synthetic ammonia utilizing the electrolysis products as feed materials;

FIG. 3 is a diagrammatic side elevation illustration of electrolysis unit constructed in accordance with the principles of this invention with detailed portions of the unit bottom wall being in section;

FIG. 4 is a bottom plan view of the unit illustrated in FIG. 3, illustrating details of the bottom wall of the unit;

FIGS. 5 and 6 illustrate another electrolyzer set up under water;

FIGS. 7 and 8 are diagrammatic side elevation views of electrolyzers positioned in land cavities and adapted to operate in accordance with principles of this invention.

When an electric current is passed through water, hydrogen ions migrate to the negative electrode (cathode) where they combine with electrons to form hydrogen atoms, which then unite to produce hydrogen molecules that escape from the water as bubbles of hydrogen gas. At the same time oxygen ions migrate to the positive electrode (anode) where they lose electrons and combine to produce water molecules and oxygen atoms which combine to form oxygen molecules and also escape from the water as bubbles. Because of the low electrical conductivity of water, solutions of sodium hydroxide or potassium hydroxide with distilled water have been conventionally employed in lieu of pure water for the electrolytic production of hydrogen and oxygen. Water electrolysis units under atmospheric pressure produce relatively large gaseous bubbles and other conditions resulting in high cell voltage requirements. As pointed out above, the actual operating voltage of commercial cells is ordinarily in the range of 2.0 to 2.3 volts at atmospheric conditions. In commercial cells operating at atmospheric conditions, power consumption in terms of direct current generally runs between 130 to 145 kwh per 1,000 scf of hydrogen produced. In most instances, direct current is obtained by rectification of alternating current, and power consumption is therefore 160 to 180 kwh per 1,000 scf on an alternating current basis.

Referring to the drawings in FIG. 1, the best mode of carrying out the invention is illustrated. In FIG. 2 a synthetic ammonia plant is shown in conjunction with the water electrolysis process to illustrate the usefulness of the present invention in other chemical works, as its general applicability will become apparent.

The electrolyzer can be any one of many presently available units. The preferable unit is of a bipolar Zdansky-Lonza design and even though much of the following is available a detailed description of various aspects thereof is given. The electrolyzer 5 is set in a submerged position with its accompanying shore and surface based auxiliary equipment.

Electric power is supplied by a high voltage three-phase AC circuit. A transformer first reduces the high voltage to a value equal to the input voltage rating of the subsequent rectifier which converts the three-phase AC current into DC current. Silicon rectifiers are preferable because of their high efficiency, their rugged construction and ease of operation. The amperage of the DC current for electrolysis is kept constant by an infinitely variable control, because the electrolysis unit has a very flat operating characteristic. Control is accomplished by means of a load tap-changing switch with continuous transducer control, within the range of approximately two transformer taps. A circuit-breaker is installed between the rectifier and the electrolysis unit to disconnect the electrolysis unit (under load) from the circuit. A low resistance resistor in series with a contractor is connected in parallel with this circuit-breaker. The purpose of this resistor is to avoid excessive current surges during starting when the electrolysis unit is not yet polarized. After a certain minimum electrolysis voltage has been reached, the resistor is short circuited by the circuit-breaker. The starting resistor also eliminates the necessity of providing the rectifier with a large reserve capacity; since the possibility of large current surges no longer exists. The electrical equipment is supervised from the surface in a remotely located central control room.

The arrangement illustrated in FIG. 1 shows one electrolysis unit 5 whereas in actual practice multiple units would very likely be employed. Each unit is composed of multiple cells indicated generally as 10.

The feed water which is pumped into the electrolysis unit to makeup the electrolytically dissociated water must be of optimum purity because contaminants would be retained in the electrolysis unit during electrolytic dissociation of the water, where they would become concentrated and ultimately disturb the electro-chemical reactions. In this respect the conditions in the electrolysis unit are the same as in any atmospheric unit. The preheated water passes through an activated carbon filter and through a demineralization unit where the water is demineralized to the extent that it has a specific resistance of 1 - 10 megohm $\times$ cm. The efficiency of demineralization is supervised automatically by conductivity control of the water. The demineralized water is supplied by pump 20 to the electrolysis unit in accordance with requirements. A pump such as 20 is placed in the line to insure that the electrolyzer can be charged with electrolyte at all times, pump 20 being capable of generating pressures in electrolyte line 25 sufficient to perform this function.

Electrolyzer 5 is provided with a containment vessel of ¼-inch thick stainless steel having a cylindrical casing 11 held between end plates 12 and 13. The electrolyte is pumped directly into channel 15 which is in communication with all cells 10 and delivers electrolyte thereto. Line 25 is open into the electrolyzer at all times and at all times contains electrolyte under pressure equal to that of the system as will be described. It is well known that hydrogen and oxygen gases can be collected and taken from an electrolyzer from two separate outlets and these are provided at 30 and 35 respectively which are stainless steel tubes taped directly into collection channels 40 and 45, the hydrogen outlet 30, and the oxygen outlet 40.

In this completely continuous system ducts 30 and 35 pass the produced gases into intermediate coolers 50 and 55 and then into separator-collectors 60 and 65. Open ducts 10 and 15 are provided and extend from collectors 60 and 65 to storage vessels 80 and 85. The latter are large storage compartments which contain a very heavy material such as sand, concrete or the like to firmly secure them on the bottom and thereby offset any buoyant effects of the gases introduced therein. The storage compartments are freely open to water thru openings 90 and 95 which are positioned at a level approximately the same as the top of the electrolyzer cells and the electrolyte located therein. Being open, the tanks can be gradually filled with water and sunk into place. Ducts 30 and 35 conduct hydrogen and oxygen into intermediary cooling

units 50 and 55 which are preferably stainless steel plenum chambers with one or more baffles to promote direction change before entering separator-collectors 60 and 65. The separator-collection chambers are similarly provided with one or more baffles extending partially from side to side effecting one or more direction changes and generally separating electrolyte. Additional electrolyte is separated as the hydrogen and oxygen travel upwardly in ducts 70 and 75 to storage compartments 80 and 85. Separation of the electrolyte is not critical in this system and may be eliminated entirely so that entrained electrolyte in the produced gaseous material is delivered into the storage compartments where it may separate from the gases and fall into the water in the storage compartment.

From the foregoing it can be seen that the system is open from a point down-line from pump 20 through the electrolyzer 5, outlet ducts 30, thru storage compartments 80 and 85 up to valves 100 and 105 in open outlet lines 110 and 115. The pressures exerted on the system are a balance between line pressure from pump 20 and water pressure acting on the gases in tanks 80 and 85. The seawater will at all times be available to the interior of the storage tanks and therefore will always create pressure approximately equal to the pressure of the ocean at the depth of the storage tanks and, more particularly, at the depth of the gas/water interface inside the storage compartments. In this manner, the pressure of the exterior environment in which the electrolyzer is operating is exerted throughout the entire electrolyte system. The storage tanks are positioned so that the level of the gas/water interface therein is at all times above the top of the electrolyte level, which is in the electrolyzer unit. This is to avoid creating an excessive pressure in the electrolyzer unit that might otherwise occur if the storage tanks or the gas/water interface were at a level lower than the electrolyte. By permitting the seawater to exert pressure on the gases produced in the storage chambers, the internal pressure of the electrolyzer is equalized to that of the exterior environment in which it resides. If for any reason excessive internal pressure in the electrolyzer is created, gases in the storage chambers will be pushed to the bottom of the storage tanks and out through seawater outlets 90 and 95 and lost, thereby preventing destruction of the equipment. From the foregoing it can be seen that the concept of equalizing the internal and external pressures of the electrolyzer is achieved while, at the same time, a novel process which is completely continuous and requires practically no shut-down or cleaning is effected.

In operation, after commissioning electrolyte is continuously available to the electrolyzer at a pressure sufficient to maintain a full capacity of electrolyte in the unit at all times. Gases which are produced consume electrolyte and move into the storage chambers. The latter are ship size for large units. As gases are produced more electrolyte automatically is available and in the event excessive pressures are created in the pressure sensors in line 25 relay the information to the surface where power is cut off. All inlet and outlet connections and lines for power, electrolyte, products of the electrolyzer, etc. are of the same construction as utilized for a surface unit, being pressure tight and capable of resisting corrosion. In underwater units commercially available brass or stainless steel materials are particularly useful.

In the storage tanks, the gas/water interface can have a material floating on the water to separate the water and gas if desired. Under very high pressures, absorption of gas in the water may cause some of the latter to be lost. The material may be a layer of plastic as a sliding piston in the tank, or a layer of oil or other suitable material.

In the case of a surface unit the gas compartments of the separators are filled with nitrogen, after which the DC current supply is opened. This permits commissioning within a few minutes and also provides for absolute safety. This process can be utilized in the present system if desired; however, the electrolyzer and chambers need only be filled with a non-compressible liquid as they are placed at the depth intended and

electrolyte pumped into the unit and started. Excessive liquid or electrolyte will be forced into the storage compartments and from there into the sea.

The DC current is supplied via bus bars to the electrolysis unit at the front end plate 12 which is the positive pole. The discharge of DC current, i.e., the negative pole is at the back plate 13 of the cell block.

Before commissioning the plant, an appropriate quantity of electrolyte corresponding to the holding capacity of the electrolysis unit is prepared in tank. Solid caustic potash is poured into the hopper of the preparation tank and dissolved with feed water. After it is dissolved, the electrolyte is admitted to the electrolysis unit. Before the electrolyte enters the electrolysis unit it passes through filter to ensure that the electrolyte is clean.

All component parts of the electrolysis unit, except the cells, are grounded through ground 120. The electrolysis unit therefore has no pipe or other connections which have to be insulated electrically. The problem of suppression of leakage current at such connections, which is experienced with other types of electrolyzers and which generally creates a considerable corrosion hazard, does therefore not exist with the subject electrolysis unit.

Each cell is sealed on both ends by embossed steel-plate walls which are nickel-plated through-out and inserted into annular frames. Nickel-plated and activated steel wire gauze is placed on the anode and cathode side of the embossed plate to serve as electrodes. Anodes and cathode compartments are separated by laminated frames of pure asbestos. The cell frames are isolated from each other by teflon covered sealing rings. Entering through duct 15 the electrolyte first passes to the cathode side of the cells, and a portion of it then continues to flow through openings in the embossed plates to the anode side. The electrolyte-gas mixture flowing upwards through the cells is collected at the cathode side in the hydrogen duct and at the anode side in the oxygen duct, and carried off. Due to the high working pressure of the electrolysis unit because of its submerged location and the resulting low specific volume of the gases, the cells can be of very narrow construction.

The cells of the electrolysis unit are assembled in blocks in the workshop. The cell blocks are delivered to the site in this preassembled condition where the connecting lines are attached and they merely have to be lowered into place and grounded. This procedure provides for simple, quick and dependable installation and recovery of the electrolysis units and minimizes the offshore operations. All materials should, of course, be selected to withstand the external environment, water for example, or the materials should be coated or otherwise protected from any anticipated deleterious effects thereof.

Individual units can have nominal capacities ranging between 5,600 - 24,500 standard cubic feet of hydrogen per hour. Larger units can be built and multiple units can be arranged in parallel. Purities of the hydrogen produced may vary between 99.8 to 99.9 percent on a volume basis and the oxygen purity may vary between 99.3 to 99.5 percent. Pressure of the gases is a function of the depth to which the electrolysis unit or units are placed.

As explained earlier, any kind of pressure cell can be used with the principles of the invention. Thus, the cells may be, for example, of the type used in the well-known cells known as the Knowles Cell, Fauser Cell, Bamag Electrolyzer, Pechkranz Electrolyzer, etc., described and illustrated in an article by C. E. Bowen, "The Production of Hydrogen and Oxygen By The Electrolysis of Water," Journal Institute Electrical Engineers (London), Vol. 90, No. 1, pp 474-85. Other suitable cells are of the type shown in Zdansky U.S. Pat. No. 2,881,123, for example, modified to include larger electrode surfaces and less exterior ring-like portions.

In FIG. 2, a source of nuclear energy is shown for producing steam and creating direct current power by means of turbines and generators and referred to generally as an energy convertor. The nuclear reactor and energy convertor apparatus are

preferably located on shore with heavily insulated conductors provided for carrying the low voltage, high amperage current to the submerged electrolyzer where they are connected by pressure-tight and electrically insulated means similar to that employed on surface high pressure units.

As shown, the electrolyzer is preferably supported from the ocean floor by a suitable platform. Other means of support may be used, as for example, sunken barges, suspension from surface platforms and the like.

Water is supplied directly to the electrolyzer from the ammonia plant which under certain process arrangements can be a byproduct in the nitrogen production phase thereof. Since the electrolyzer will operate continuously and under pressure, the water pressure must be increased enough above its own hydrostatic pressure to enter the electrolyzer. After the electrolyzer is initially charged with electrolyte, only slight adjustment of the chemical make-up is normally periodically required, and this may be conveniently done through the connecting line used to transmit feed water to the electrolyzer.

In the particular illustration used to depict the invention in FIG. 2, the high pressure hydrogen and oxygen are conducted through piping back to the shore for use in ammonia synthesis in a known manner, or stored under pressure in either the liquid or gaseous state at any suitable depth desired in a storage tank, suspended from surface apparatus, or otherwise suitably stored below the surface, or in any event preferably under super-atmospheric pressure conditions. The same is true of the synthetic ammonia produced. The latter novel concept of handling ammonia, may be employed to eliminate the need for pressurized or refrigerated surface storage.

In this embodiment of the invention, the bottom wall 225 of container 220 is provided with means for equalizing the internal and external pressures of the electrolyzer. Thus wall 225 has an opening 230 formed therein over which a flexible diaphragm 235 is positioned (preferably $\frac{1}{4}$ inch rubber). The diaphragm, which may be of any shape desired, (shown in this embodiment as a circular member) is fixed over the opening by a sealing ring 240 and bolts 242, adapted to tightly seal the edge of diaphragm 235 to the inner side 245 of wall 225. The diaphragm is preferably made from rubber, although plastics and metals capable of withstanding chemical attack from both internal and external media, being flexible enough to respond to pressure differentials between the interior and exterior in excess of 4 p.s.i. for example, and capable of providing an effective seal with wall 225 when tightly secured thereto.

In operation, the vessel 220 will be filled with electrolyte and gases and due to the flexibility of diaphragm 235, the pressure inside the electrolyzer will be substantially the same as the hydrostatic pressure of the sea. The operating pressure may, therefore, be selected to correspond with a particular depth, or vice versa. The flexible diaphragm need not be capable of equalizing the internal and external pressures exactly, but should tend to accomplish this, and thereby create the desired super-atmospheric condition desired internally.

Various means may be employed to install the above-described apparatus on the ocean floor, including, but not limited to, mechanically pressurizing the electrolyzer interior to approximate the exterior pressure as it is gradually lowered into place, to the extent necessary to prevent excess internal or external stresses from developing during installation. Another method is to fill the electrolyzer with a relatively incompressible liquid, electrolyte for example, to prevent collapse.

As another example of a system utilizing the principles of this invention reference is made to FIGS. 5 and 6.

The mixtures of electrolyte and hydrogen and electrolyte and oxygen leave the cell blocks through ducts 159-H and 159-O respectively, pass through bends 160, and intermediary coolers 161 and then enter gas separators 162 and 163, where the gases are separated from the circulating electrolyte. The hydrogen ascends in the hydrogen separator 162, passes through drop separator 164 to separate entrained electrolyte droplets, passes through the line cooler 165 and finally leaves

through control valve 166. The oxygen ascends in the oxygen separator 163, through the drop separator 167, passes through the line cooler 168 and finally through control valve 169 to consumption or surface storage. Instead of bringing the O_2 and H to surface immediately underwater storage under pressures approximately equal to that of the material leaving the separators may take place with the O_2 or H, being introduced into an empty storage compartment similar in construction to the pressure equalizing unit of FIG. 1, for example. Due to the temperatures and pressures involved, hydrogen and oxygen isotopes may exist and these can be separated and removed before using the O_2 and H liquids or gas. From gas separators 162 and 163 the electrolyte passes to recycle pump 170, which returns the electrolyte through filter 171 back to the cells, through pressure equalizer 172.

The interior pressure of the electrolyzer is maintained at the ambient water pressure by equalizer 172 having an open side 172A and impervious diaphragm 172B which is in contact with the electrolyte in the line from pump 171 and filter 172. Diaphragm 172B is preferably rubber one-half inches thick held in a sealed manner within the chamber by any suitable means. Chamber 172C formed by diaphragm 172B and the closed end cylindrical wall of equalizer 172 is approximately one-tenth to one-half the size of the electrolyzer containment vessel with which it is associated, in this case vessel 181. The pressure equalizer is mainly concerned with maintaining a more or less constant pressure in the containment vessel corresponding to its exterior superatmospheric environment. Forced circulation of the electrolyte provides for intimate mixing of anolyte and catholyte, so that discrepancies in the concentration of the electrolyte in the anode and cathode compartments of the cells are eliminated. This also ensures that all cells are uniformly supplied with an adequate quantity of electrolyte. The electrolyte filter provides continuous purification of the circulating electrolyte. The filter is equipped with a number of perforated filter tubes which are fitted into a perforated tray and covered with dense filter cloth. The liquid passes through the filter cloth and the perforated tray and finally through a filter cylinder which is an additional safeguard to prevent the ingress of impurities into the cells.

Internal pressure relief in the event of excessive working pressure in the electrolysis unit is effected by pneumatic pressure controller 173 which operates diaphragm valve 166 installed in the hydrogen line. The controller is a pressure sensor which operates to open the hydrogen line in the event a predetermined excessive pressure is reached within the unit. The electrolyte level in the gas separators is kept constant by level controller 174 which controls the electrolyte level in oxygen separator 163. This controller operates diaphragm valve 169 which opens or closes as a function of the level in the oxygen separator. Since both separating drums 162 and 163 are connected by a number of communicating pipe bends 175 below the liquid surface, the maintenance of a constant level in the oxygen separator also keeps the level in the hydrogen provided with a pressure relief valve which opens in the event the pressure rises above the safe working pressure of equalizer chamber 172 and also limits the pressure.

Provisions are also provided to prevent the ingress of hydrogen from separator 162 into the oxygen compartment of separator 163. This is effected by the control of the electrolyte level in the separators. If the level in one separator drops as a result of a failure, for instance, of the level controller, electrical switch 178 is operated and disconnects the DC current supply. This eliminates further level variations because no more gas is produced. The isolating switch also operates an audible and visible alarm. Direct-acting float valve 179, is provided as an additional protection, and opens the separator in which the electrolyte level has dropped as a result of the failure thus allowing the gas to escape. This causes a slight pressure drop in that separator whereby the levels in the two separators come into balance again.

The foregoing description has been made in connection with apparatus adapted to be employed in the ocean. Any

body of water of adequate depth may be used, however. The oceanic environment has several advantages in that it is freely available, great depths may be easily found if desired, and for a given depth, a given pressure environment exists and will remain constant. Nevertheless, the present invention may utilize other geological features, as for example, a mined or drilled land cavity, or a cavity which has formed from erosion, volcanic activity, or any other cause.

FIG. 7 illustrates another embodiment of this invention wherein an electrolyzer 298 with cell 299 is assembled or otherwise positioned in a cavity 300 in a rock formation 304, which is preferably of a relatively impermeable nature. The cavity may be lined with plastic or ductile metal or otherwise rendered impermeable if this is a problem however. The cavity is provided with an entrance passage 308 having a closure 312 anchored and sealed at 314 and 316 against the inner wall of passage 308. The closure and interior of the cavity form a pressure vessel which may be pressurized by introducing a second medium through passage 320. The pressurizing medium may be pumped through passage 320 or passage 320 may be a standpipe bored through strata overlying formation 304 to create a static head when filled with the pressurizing medium. If higher pressures are desired, the specific gravity of the medium may be increased. For example, by dissolving into a liquid or mechanically dispersing some additives such as Barogel or other barite material, a greater static head and consequently a higher pressure may be achieved in cavity 300.

As shown, electrolyzer 298 is comprised of essentially the same elements as the electrolyzers illustrated above and is held in position by insulated supports 324. As illustrated, oxygen and hydrogen conduits are connected with the gas collecting zone 328, and run through closure 312 and passage 308 to storage or consumption as desired. Water and electricity are supplied through suitable conduits which also run through passage 308 and closure 312 to the electrolyzer. All of these conduits are run through sealed openings in closure 312 and are adapted to be disconnected when it is desired to open closure 312, for example, in the event of shutdown and repair of the electrolyzer.

In addition to pressurizing cavity 300 by introduction of a liquid, other methods of obtaining pressure may be achieved. Mechanical compression of a liquid has already been mentioned. The cavity may also be filled with liquid or suitable gas and heat or heat generating materials, introduced to expand and create pressure or material may be introduced into the cavity and thermally and electrolytically decomposed to increase pressure. Electrolysis of water is one example. Still another method is to introduce materials into cavity 300 and cause them to react chemically and expand to increase pressure.

In FIG. 8, another arrangement of the system shown in FIG. 7 is represented. In this particular arrangement, the electrolyzer 330 with cells 332 which is essentially the same as that described above in connection with FIG. 7, is supported by insulated supports 334 from the roof of cavity 338. A passage 342, through formation 348 to cavity 338, is provided for initially installing the electrolyzer and subsequently passing the hydrogen, oxygen, direct current and water conduits

therethrough. Closure 352 which is essentially the same as closure 312 in FIG. 7, is located in passage 342. A conduit P is indicated passing through closure 312 and passage 348 and is adapted to provide pressurized liquid or materials suitable for pressurizing cavity 338 in accordance with any of the methods above-mentioned in connection with FIG. 7.

Where suitable geological formations such as formations 304 and 348 are not available for creating a high pressure chamber, a cavity may be drilled into the earth, with a rotary drilling technique. The bore hole may be enlarged at its lower extremity by washing, for example, as in salt dome formations or by explosion techniques known in the petroleum industry and under the A.E.C.'s "Plowshare Program." Bore holes on the order of 48 inches in diameter may presently be conventionally drilled and even larger holes may be created by special techniques to permit the original equipment to be lowered into the cavity, assembled and operated.

Still another available cavity would be an abandoned mine in which vertical and horizontal shafts are available for the entrance of men and machinery.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by United States Letters Patent is:

1. A method of carrying out an electrolytic process for producing gases in an electrolyzer comprising at least one electrolytic cell and a containment vessel therefor, said method comprising supplying electric power to said electrolyzer from an external source during operation thereof, subjecting said vessel to an external superatmospheric hydrostatic pressure, continuously charging said electrolyzer with electrolyte under pressure and while operating said electrolyzer regulating the internal operating pressure of the continuous electrolytic system by collecting the produced gases external to said electrolyzer and exerting external hydrostatic pressure against said collected gases generated and being in fluid communication with the interior of said electrolyzer so that said internal and external pressures are approximately the same during said operating.

2. A method as defined in claim 1 wherein said electrolyzer is located below the surface of a body of water during operation, and said gases are separately collected in compartments and subjected to pressure approximately equal to said internal operating pressure of said electrolyzer.

3. A method as defined in claim 2 wherein said electrolyte is water, said gases generated are hydrogen and oxygen, and the latter are transmitted in free flowing conduits from said electrolyzer to separate compartments located at approximately the same depth as said electrolyzer and open in the lower portion thereof whereby said gases are pressurized at substantially the same pressure as that of said body of water.

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