

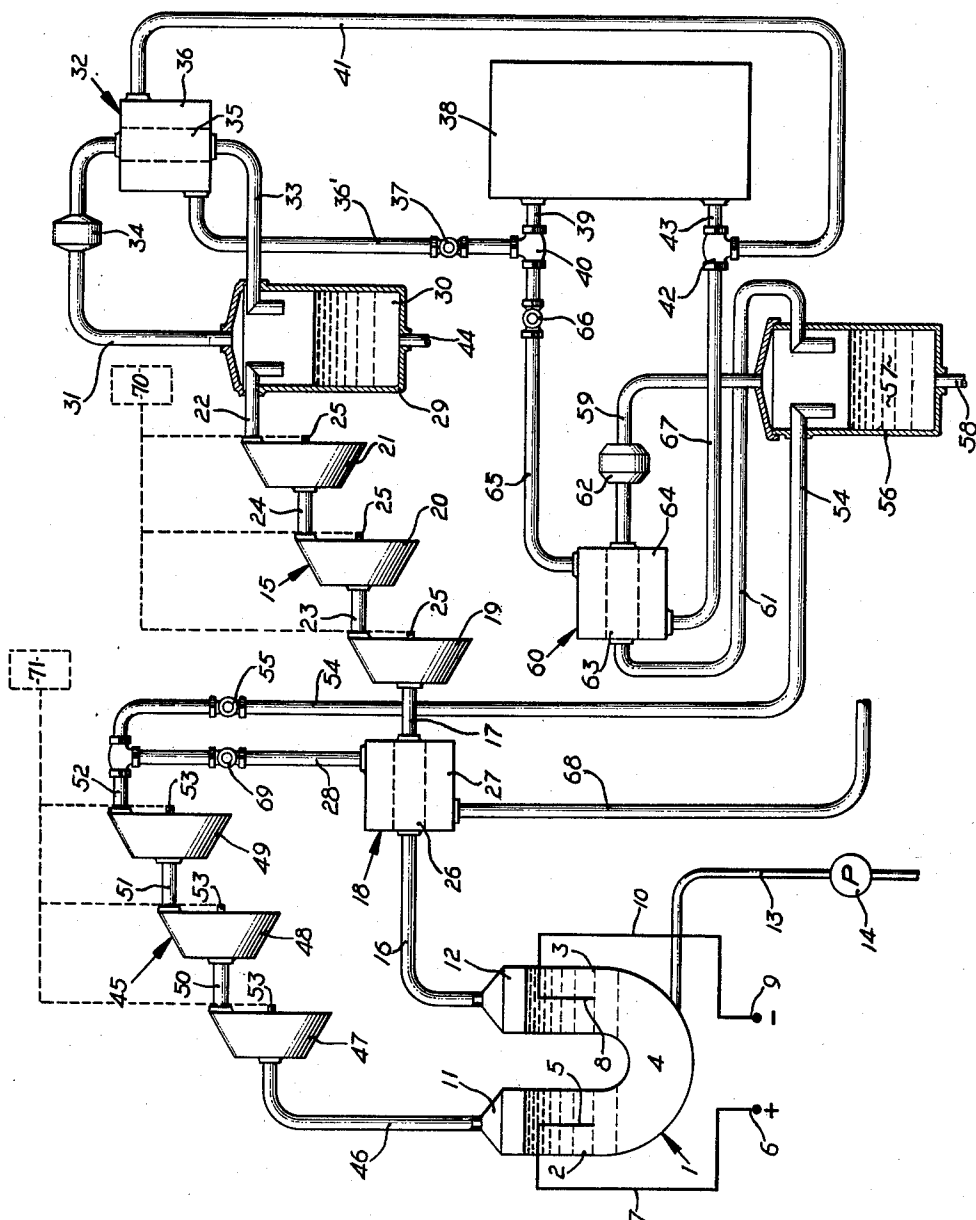
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PRODUCTION OF LOW TEMPERATURE LIQUIDS

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## PRODUCTION OF LOW TEMPERATURE LIQUIDS

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This invention relates to a method and apparatus for the production of low temperature liquids and more particularly to the production of liquid hydrogen and oxygen through the electrolysis of water.

At present, low temperature liquid gases are produced by starting with a single gas at atmospheric temperature and pressure and compressing the gas to a high pressure and temperature. Thereafter the gas is cooled and then expanded to produce a liquid. However, by the present invention, it is proposed to simultaneously produce gaseous hydrogen and oxygen at ambient temperature and at very high pressures through the electrolysis of water under controlled conditions. Thereafter, both the gases can be expanded through power developing units in order to reduce the temperature of the gases to the liquifying point. If it is desired to liquify approximately equal parts by weight of hydrogen and oxygen, a portion of the expanded oxygen can be exhausted through a heat exchanger to thereby further reduce the temperature of the hydrogen. Also, it is possible to utilize a very low temperature cryostat to liquify the gases remaining after expansion through the power developing units. It is understood that the invention is not limited to the liquification of hydrogen and oxygen but is equally applicable to the liquification of any two or more gases which can be produced simultaneously under pressure in any manner such as by chemical or electrical process.

It is therefore an object of the present invention to provide a process and apparatus for producing gases simultaneously and thereafter liquifying each of the gases.

Another object of the invention is to produce gaseous hydrogen and oxygen under pressure and thereafter separately liquify each of the gases.

A further object of the invention resides in the production of a gas under pressure by introducing the gas to a power developing unit and recirculating the non-liquified exhausted gas through a cooling unit.

Another object of the invention resides in the production of gaseous hydrogen and oxygen under pressure by the electrolysis of water.

A still further object of the invention is to expand a plurality of gases under pressure and utilize one of the exhausted gases to cool another of the gases.

These and other objects of the invention, not specifically set forth above, will become readily apparent from the accompanying description and the drawing.

Referring to the drawing, wherein one form of the invention is diagrammatically illustrated, a U-shaped electrolysis unit 1 has legs 2 and 3 and contains a quantity of water 4 plus an acid or alkaline solution to form an electrolyte. An anode 5 is immersed in the water in leg 2 and is connected to positive terminal 6 of a direct current source by means of line 7. Also, a cathode 8 is immersed in the water in leg 3 and is connected to negative terminal 9 of the same direct current source by means of line 10. It is therefore apparent that electrolysis of the water will take place when a high enough voltage is applied by the direct current source between ter-

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minals 6 and 9 and that the amount of water which is electrolyzed in any given period of time will depend upon the current flow from terminal 6 to terminal 9.

During electrolysis of the water, oxygen gas will form at the anode 5 and will rise into the space 11 above the water level in leg 2. Also, hydrogen gas will form at the cathode 8 and will rise into space 12 above the water level in leg 3. In order to replenish the supply of water in unit 1, a water supply (not shown) is connected to the unit 1 by passage 13 in which is located pump 14. It is well known in the art to electrolyze water by means of the apparatus just described.

The space 12 is connected to a power developing unit 15 through passages 16 and 17 and heat exchanger unit 18. The unit 15 is divided into a number of stages, 19, 20 and 21 and the first stage 19 connects with passage 17, while the last stage 21 exhausts to a low pressure through passage 22. The intermediate stage 20 is connected to the first stage 19 by a passage 23 and to the last stage 21 by a passage 24. Each of the stages has an output shaft 25 which can be connected to a common load (not shown) driven by the stages. While each of the stages is illustrated as a turbine, it is understood that any suitable type of expansion engine can be used for one or more of the stages and that the unit 15 can be comprised of a single stage rather than a plurality of stages.

Because of the load placed upon unit 15, it is apparent that the pressure of the hydrogen gas in space 12 will build up until it is sufficient to drive the load and, of course, by varying the load on the unit 15, the pressure of the gas in space 12 can be varied and therefore controlled. It is desirable to have a pressure of between 2,000 and 4,000 p.s.i. in space 12 so that a high degree of cooling will result in the expansion of the hydrogen gas through unit 15. The high pressure gas in space 12 will be at ambient temperature since no work is done on the gas to compress it to these high pressures. In prior liquification systems, the temperature of a single gas is substantially increased above the ambient temperature before expansion because of the work done on the gas to increase its pressure and this increase in temperature must be removed at some point in the process of liquification.

The high pressure gas at ambient temperature passes through the central passage 26 of heat exchanger unit 18 and the outer chamber 27 of the unit is connected through passage 28 with oxygen which has been cooled to a very low temperature in a manner which will be later described. Thus, the temperature of the hydrogen gas entering the first stage 19 of the unit 15 will be reduced substantially below ambient temperature. The expansion of the gas through stages 19, 20 and 21 will greatly reduce the temperature of the gas in accordance with the laws of thermodynamics so that the temperature in exhaust passage 22 will be at approximately the liquification temperature of hydrogen and the exhaust passage will contain a mixture of hydrogen gas and liquid hydrogen particles. Of course, the pressure in space 12 and the amount of cooling in heat exchanger unit 18 can be regulated in order to control the temperature in exhaust passage 22.

The passage 22 introduces the lower temperature hydrogen gas and liquid particles into the interior of vessel 29 and of course the liquid particles will form a liquid hydrogen body 30 in the vessel. The portion of the hydrogen entering vessel 29 which is in gaseous form will be circulated through passage 31, heat exchanger unit 32, and return passage 33 by a blower 34 located in passage 31. The hydrogen gas enters the central passage 35 of the unit 32 while the outer chamber 36 receives a very low temperature fluid, such as helium, from passage 36', containing a regulating valve 37. The

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passage 36' connects with the discharge side of a cryostat 38 through passage 39 and connection 40. A return passage 41 connects the chamber 36 with the return side of the cryostat 38 through connection 42 and passage 43. The cryostat 38 can be of any well-known construction and can operate on the usual refrigeration cycle in order to produce very cold fluid at temperatures capable of liquifying at least a portion of the cold hydrogen gas passing through heat exchanger unit 32. The hydrogen which is liquified by unit 32 will return to vessel 29 and become associated with the liquid body 30 and that portion of the hydrogen which returns from unit 32 to the vessel in gaseous form will be mixed with the incoming hydrogen gas from passage 22 and then recirculated through the unit by blower 34. Through the regulation of valve 37, it is possible to regulate the amount of cooling medium supplied to the unit 32 from the cryostat so that sufficient cooling medium will be utilized to reduce all of the hydrogen gas from passage 22 to liquid form. A suitable drain 44 is connected to vessel 29 in order to remove the liquid hydrogen as it is produced.

The liquid oxygen is produced in a manner similar to the production of liquid hydrogen. The space 11 is connected to power developing unit 45 through passage 46 and the unit 45 is divided into a number of stages 47, 48 and 49. The intermediate stage 48 is connected to the first stage 47 by passage 50 and to the last stage 49 by a passage 51 and the last stage exhausts to a low pressure through passage 52. Each of the stages has an output shaft 53 which can be connected to a common load (not shown) driven by the stages. As noted in connection with power unit 15, each of the stages are shown as a turbine but any suitable type of expansion engine can be used for one or more of the stages and, of course, a single stage could be utilized to replace the plurality of stages.

Because of the load placed upon unit 45, it is apparent that the pressure of the oxygen gas in space 11 will build up until it is sufficient to drive the load on unit 45 and, of course, by varying the load on unit 45, the pressure of the gas in space 11 can be varied and therefore controlled. As in the case of space 12, it is desirable to have a very high pressure in space 11, such as a pressure between 2,000 and 4,000 p.s.i., so that a high degree of cooling will result in the expansion of the oxygen gas through unit 45. It is apparent that any well known means can be provided, if necessary, for electrolysis unit 1 to prevent unsatisfactory pressure differences between spaces 11 and 12 and also, the capacity of units 15 and 45 can be selected to accomplish the same purpose. Since the gas in space 11 is produced at ambient temperature, the gas will immediately drop to below ambient temperature upon expansion through the first stage. Upon exhaust from the last stage, the temperature of the oxygen will approach the liquification temperature and passage 52 will contain a mixture of oxygen gas and liquid oxygen particles.

The exhaust passage 52 connects with a passage 54, which contains valve 55 and which introduces the low temperature oxygen gas and liquid particles into the interior of vessel 56. The liquid particles will collect in the vessel to form liquid body 57 which can be removed from the vessel as desired through drain pipe 58. The portion of the oxygen entering vessel 56 in gaseous form will be circulated through passage 59, heat exchanger unit 60, and return passage 61 by a blower 62 located in passage 59. The oxygen gas enters the central passage 63 of the unit 60 while the outer chamber 64 receives the very low temperature cooling fluid, such as helium, from passage 65 which contains regulating valve 66. The passage 65 connects with the discharge passage 39 of cryostat 38 through connection 40. A return passage 67 connects the chamber 64 with return passage 43 of the cryostat through connection 42. The cooling fluid produced by the cryostat is at sufficiently low temperature to

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liquify at least a portion of the cold oxygen gas which is passed through the heat exchanger unit 60. The oxygen which is liquified by unit 60 will return to vessel 56 and become associated with the liquid body 57 and that portion of the oxygen which returns from unit 60 to vessel 56 in gaseous form will be mixed with the incoming oxygen gas from passage 54 and recirculated through unit 60 by blower 62. Thus, all of the oxygen gas will be liquified and by regulating valve 66, it is possible to provide sufficient cooling medium to unit 60 to assure this result.

During the electrolysis of the water, more oxygen than hydrogen by weight is produced and if it is desired to liquify approximately the same amounts of hydrogen and oxygen, the excess oxygen can be exhausted from passage 52 through passage 28, heat exchanger unit 18 and passage 68. The passage 28 contains a valve 69 for regulating the quantity of oxygen exhausting from passage 68. It is apparent that the exhaust oxygen passing through chamber 27 of unit 18 will substantially reduce the temperature of the high pressure hydrogen gas passing through central passage 26 to the power developing unit 15 and reduce the amount of cooling medium required in unit 32 to complete the liquification of all the hydrogen gas. The valves 55 and 69 can, of course, be regulated to adjust the quantities of expanded oxygen which will be liquified and which will be exhausted through unit 18.

The valves 37 and 66 can be regulated to distribute the output of the cryostat between heat exchanger units 32 and 60, respectively, so that complete liquification of both the hydrogen and oxygen is obtained. Since certain passages in the apparatus contain both gas and liquid particles of either hydrogen or oxygen, these passages are so arranged that the liquid can drop through the passage under gravitational force and thus, pumping means can be eliminated. The power developed by units 15 and 45 can be dissipated by having shafts 25 and 53 drive adjustable load, friction clutches 70 and 71, respectively, of well known construction or the power can be utilized to operate cryostat 38 or to provide the direct current source between terminals 6 and 9.

By the present invention, an apparatus and method is provided for simultaneously obtaining two gases under pressure and thereafter liquifying both of the gases. It is understood that the total quantity of both gases can be liquified rather than using a portion of one gas to cool the other. Thus, all of the oxygen could be liquified and the heat exchanger unit 18 eliminated. Any suitable apparatus can be utilized for the power developing units, the heat exchanger units and the cryostat. Various other modifications are contemplated by those skilled in the art without departing from the spirit and scope of the invention as hereinafter defined by the appended claims.

What is claimed is:

1. A method for simultaneously producing liquid hydrogen and liquid oxygen comprising simultaneously producing hydrogen gas and oxygen gas under pressure in separate spaces by the electrolysis of water, supplying the gas in each of said spaces to a separate power producing unit, placing a load upon each power unit to select the pressure of the gas in each space, and expanding each of said high pressure gases through its associated power unit to reduce the temperature of each gas to the temperature of liquification so that the exhaust from one power unit will contain at least some liquid hydrogen and the exhaust from the other power unit will contain at least some liquid oxygen.

2. A method as defined in claim 1 including the step of circulating the low temperature gas in the exhaust from each power unit through separate cooling units to completely liquify each of the expanded gases.

3. A method as defined in claim 1 including the step of exhausting a portion of the expanded oxygen to atmosphere through a cooling unit in order to reduce the tem-

perature of the hydrogen gas at the entrance to its associated power unit.

4. A method for simultaneously producing low temperature hydrogen and oxygen comprising simultaneously producing hydrogen and oxygen gas in separate spaces by the electrolysis of water, supplying the gas in each of said spaces to a separate power producing unit, placing a load upon each power unit, adjusting the load upon each power unit to obtain a gas in each space at a selected high pressure and expanding each of said high pressure gases through its associated power unit to produce low temperature hydrogen exhaust from one power unit and to produce low temperature oxygen exhaust from the other power unit.

5. An apparatus for producing low temperature hydrogen and oxygen comprising means for producing hydrogen and oxygen gas by the electrolysis of water, said producing means having separate spaces for the hydrogen and oxygen gas, a separate power producing means connected to each of said spaces and driven by the expansion of the gas from the space through said power means, adjustable load means connected with each of said power means for maintaining the gas in each space at a selected high pressure, and separate means for collecting the lower temperature hydrogen exhaust from one power means and for collecting the low temperature oxygen exhaust from the other power means.

6. An apparatus for producing liquid hydrogen and liquid oxygen comprising means for producing hydrogen and oxygen gas under pressure by the electrolysis of water, said producing means having separate spaces for the hydrogen and oxygen gas, a separate power producing means connected to each of said spaces to be driven by the expansion of the substance in each space, load means connected with said power means for maintaining the pressure in each space while the gas therein remains at ambient temperature, and separate means for collecting liquid in the exhaust from each power means, each of said collecting means comprising a liquid tank for receiving the liquid portion of said exhaust and cooling means for liquefying the gaseous portion of said exhaust, each of said cooling means comprising a heat exchanger unit having its inlet and outlet connected to one of said tanks above the liquid level, blower means for circulating the gaseous exhaust through each of said units and cryostat means connected to said units for supplying the cooling medium to liquefy the gaseous exhaust.

7. An apparatus as defined in claim 6 having valve means for regulating the amount of cooling medium supplied to each heat exchanger unit.

8. An apparatus for producing liquid hydrogen and liquid oxygen comprising means for producing hydrogen and oxygen gas under pressure by the electrolysis of water, said producing means having separate spaces for the hydrogen and oxygen gas, a separate power producing means connected to each of said spaces to be driven by the expansion of the substance in each space, load means connected with said power means for maintaining the pressure in each space while the gas therein remains at ambient temperature, separate means for collecting liquid in the exhaust from each power means, a heat exchanger unit for cooling the gaseous hydrogen prior to expansion through its associated power means and means for supplying a portion of the exhausted oxygen through said heat exchanger unit.

9. An apparatus as defined in claim 8 having valve means for regulating the portion of exhausted oxygen supplied to said collecting means and to said heat exchanger unit.

10. A method for simultaneously producing liquid hydrogen and liquid oxygen comprising simultaneously separately producing hydrogen gas and oxygen gas by the electrolytic dissociation of water under pressure, expanding each of said gases through separate power producing means so that the exhaust from each power producing means is at extremely low temperature collecting the low temperature liquid in the exhaust from each power producing means, and circulating the low temperature gas in the exhaust from each power producing means through a cooling zone to completely liquefy each gas.

11. A method for simultaneously producing liquid hydrogen and liquid oxygen comprising simultaneously separately producing hydrogen gas and oxygen gas by the electrolytic dissociation of water under pressure, expanding each of said gases through separate power producing means so that the exhaust for each power producing means is at extremely low temperature, collecting the low temperature liquid in the exhaust from each power producing means and cooling the hydrogen gas prior to expansion with a portion of the expanded oxygen.

12. An apparatus for producing liquid hydrogen and liquid oxygen comprising means for simultaneously producing hydrogen gas and oxygen gas under pressure by the electrolytic dissociation of water under pressure, first power developing means connected with said producing means for expanding the hydrogen gas to the liquefaction temperature of hydrogen, second power developing means connected with said producing means for expanding the oxygen gas to the liquefaction temperature of oxygen, and separate collection means for collecting liquid in the exhaust from each of said power developing means, each of said collection means comprising a liquid tank for receiving the liquid portion of the exhaust and cooling means for liquefying the gaseous portion of said exhaust.

13. An apparatus for producing liquid hydrogen and liquid oxygen comprising means for simultaneously producing hydrogen gas and oxygen gas under pressure by the electrolytic dissociation of water under pressure, first power developing means connected with said producing means for expanding the hydrogen gas to the liquefaction temperature of hydrogen, second power developing means connected with said producing means for expanding the oxygen gas to the liquefaction temperature of oxygen, separate collection means for collecting liquid in the exhaust from each of said power developing means, and cooling means for cooling the hydrogen gas prior to expansion through said first power developing means with a portion of the oxygen exhausted from said second power developing means.

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