Abstract:

A system and method for efficient production of hydrogen.

Declarations under Rule 4.17:

- of inventorship (Rule 4.17(iv))
- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

Title: A SYSTEM AND METHOD FOR EFFICIENT PRODUCTION OF HYDROGEN

Diagram:

**FIGURE 1**

Abstract:

A system (100, 200) and methods thereof provide an on-demand practical, economical and safe thermo-chemical process for the production and storage (170) of clean hydrogen gas and deuterium. There is made use of a mixture of chemicals, metals and catalysts in a reactor (140) that produce a chemical reaction. Specifically hydrogen production consists of causing a reaction of a metal, for example, Aluminum (Al) or different alloys thereof, with sea, saline or regular water (110), in the presence of one of a particular list of acids and alkali, for example Na OH or AlCl₃ (120, 220) used as an enhancer. Depending on the enhancer used, the system (100) may provide usable byproducts (180) and/or recycle (180) the enhancer.
A SYSTEM AND METHOD FOR EFFICIENT PRODUCTION OF HYDROGEN

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 61/620,642 filed April 5, 2012.

BACKGROUND

1. Field of the Invention

This invention relates to a technology for production of hydrogen and deuterium (heavy hydrogen) from sea water, saline water and regular water.

2. Prior Art

It is well known that hydrogen can be produced from a wide variety of resources, which include coal, oil, natural gas, biomass and water using a variety of process technologies. Such production technologies include, for example, water electrolysis and reforming of fossil fuels. Electrolysis requires large amounts of energy and is presently considered to be significantly more expensive commercially than reforming. Reforming involves extraction of molecular hydrogen from fossil fuels, such as natural gas. Such processes may be complex and usually result in residues, such as carbon dioxide. To be economically viable hydrogen production via reforming has to be done in large plants, which create a necessity for hydrogen storage and transportation, while safe, reliable and low cost options for hydrogen storage and delivery are currently not available.

Other methods of hydrogen production include thermo-chemical water splitting using chemicals and heat in multiple steps; photo-electrochemical water splitting using
semiconductor material exposed to the Sunlight; and, bio-photolysis of water using microorganisms. Each of these alternative methods of hydrogen production has at least one the following disadvantages of high cost, high energy consumption, low yield and low throughput, or long start-up times.

It would therefore be advantageous to provide a solution for the production of hydrogen, or for that matter deuterium (heavy water) that overcomes the deficiencies of prior art solutions. It would be further advantageous if the production of such hydrogen or deuterium would be possible in a variety of manufacturing plant scales to allow for safe production also close to consumption areas.
BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter that is regarded as the invention is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other objects, features, and advantages of the invention will be apparent from the following detailed description taken in conjunction with the accompanying drawings.

Fig. 1 is a schematic diagram of an embodiment of an apparatus for manufacturing hydrogen with recycling of the active material according to an embodiment.

Fig. 2 is a schematic diagram of an embodiment of an apparatus for manufacturing hydrogen with a useable byproduct according to an embodiment.

Fig. 3 is a flowchart of a manufacturing process according to an embodiment.
DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

It is important to note that the embodiments disclosed by the invention are only examples of the many advantageous uses of the innovative teachings herein. In general, statements made in the specification of the present application do not necessarily limit any of the various claimed inventions. Moreover, some statements may apply to some inventive features but not to others. In general, unless otherwise indicated, singular elements may be in plural and vice versa with no loss of generality. In the drawings, like numerals refer to like parts through several views.

A system and methods thereof provide an on-demand practical, economical and safe thermo-chemical process for the production and storage of clean hydrogen gas and deuterium. There is made use of a mixture (S310) of chemicals, metals and catalysts in a reactor 140 that produces a chemical reaction. Specifically hydrogen production consists of causing a reaction of a metal, for example, Aluminum (Al) or different alloys thereof, with sea, saline or regular water, in the presence of one of a particular list of acids and alkali, for example NaOH or AlCl₃ used as an enhancer. Depending on the enhancer used, the system 100 may provideusable byproducts and/or recycle the enhancer.

Reference is now made to Fig. 1 that depicts an exemplary and non-limiting schematic diagram of an embodiment of an apparatus 100 for manufacturing hydrogen (H₂) with recycling of the active material according to the invention. The apparatus 100 comprises a water source 110, the water source may supply fresh water, saline water or sea water. An enhancer source 120 that contains an enhancer used according to the process for the manufacturing of hydrogen. The apparatus 100 further comprises a reactor 140-1 that may further allow cooling of the reactor 140-1 if and when needed. In one embodiment
of the invention a plurality of reactors are used so as to allow for a more favorable throughput of the apparatus 100, for example, a reactor 140-2 is added. According to the invention into the reactor 140-1 there are added the water via pipe 115, the enhancer via pipe 125, and scrap aluminum (S3 10 in Fig. 3). It is assumed that scrap aluminum is loaded into the reactor 140-1 and such process is not shown herein as it would be obvious to one of ordinary skill in the art. Such addition of the scrap aluminum into the reactor 140-1 may be either manual or automatic and both are considered an integral part of the invention. In the process the reactor 140-1 may heat and therefore cooling may be required and applied appropriately. The entry of materials into the reactor 140-1 is controlled by valves 180-1 and 180-3, typically under the control of the controller 190, the details of which are explained herein below. In the reactor 140-1 a chemical process takes place where hydrogen is released and transferred via pipe 145 when the valve 180-5 is set appropriately to allow the hydrogen rich atmosphere to be released via pipe 145 into the condenser 150 (S320 in Fig. 3). In the condenser 150 vapors are removed, for example, water vapors. The hydrogen rich atmosphere is then moved through a filter 160 (S330 in Fig. 3) before being stored in a hydrogen storage 170 (S350 in Fig. 3), which may be, for example and without limitation, a canister appropriate for the storage of hydrogen. Such hydrogen may be later released from the hydrogen storage 170 by means of valve 180-9, typically under the control of controller 190. The filter 160 may include a mechanical filter to clear the hydrogen rich atmosphere from the contamination of particles (optional S340 in Fig. 3). The filter 160 may further or alternatively contain a chemical filter for the purpose removing gasses other than hydrogen. Periodically the reactor 140-1, typically by opening the valve 180-7, under the control of controller 190, releases the A1C13 + H2O formed in the reactor and recycle them into the active material storage 130 via pipe 185. By doing so the active material is recycled and reused.
Fig. 2 depicts an exemplary and non-limiting schematic diagram of an embodiment of an apparatus 200 for manufacturing hydrogen with a useable byproduct according to the invention. Like parts to those described with respect of Fig. 1 are not repeated herein. As there is no recycling shown in this figure, element 130 and the pipe 185 leading thereto have been removed from this figure. The apparatus 200 uses a different enhancer, for example and without limitations, NaOH 220. While the process under the control of controller 190 resembles that which was described hereinafore with respect of Fig. 1, the difference is in the byproduct produced in the reactor 140-1. When the NaOH enhancer 220 is used the resultant byproduct is A1203 a most desirable byproduct that contributes to the overall commercial worthiness of the apparatus 200. The use of a second reactor allows the alternating between the two reactors so that when one is in the process of releasing hydrogen the other reactor is cleared from its byproducts, may they be for recyclable purposes as discussed with respect of Fig. 1 above, or for the purpose of disposal of the useable by product as shown with respect of Fig. 2. While the invention is disclosed with respect of the use of either NaOH or A1C13 as the enhancers, other enhancers may be used including, but not limited to, A1C13X6H2O, H2SO4, A12SO4, KOH, Ca(OH)2. Moreover, while the principles of the invention where disclosed with respect of the production of hydrogen one of ordinary skill in the art would not be unduly burdened to use these principles for the manufacturing of deuterium.

According to embodiments of the invention the following reactions are suggested:

\[ \text{A1}_2\text{O}_3 + 6\text{HCl} = 2\text{A1C1}_3 + 3\text{H}_2\text{O} \]
that is intended for the reduction of an oxide layer off of the metal, e.g., aluminum, which is done by using an acid solution having a low concentration that is sufficient to remove the oxide film from the metal surface.

\[2\text{Al} + 3\text{H}_2\text{O} + 6\text{HCl} = (2\text{Al}(\text{OH})_3 + \text{HCl})\]

\[2\text{AlCl}_3 + 3\text{H}_2\text{O} + 3\text{H}_2 + Q (\text{AlCl}_3 \text{for recycling of Al})\]

or

\[2\text{Al} + 3\text{H}_2\text{O} + \text{AlCl}_3 \times 6\text{H}_2\text{O} = 2\text{AlCl}_3 + 6\text{H}_2\text{O} + 3\text{H}_2 + Q \text{(exothermic reaction with release of additional energy).}\]

HCl (low concentration)

\[2\text{Al} + 6\text{H}_2\text{O} = 2\text{Al}(\text{OH})_3 + 3\text{H}_2 + Q (\text{exothermic reaction with release of additional energy}).\]

\[\text{Al(OH)}_3 + 3\text{HCl} = \text{AlCl}_3 + 3\text{H}_2\text{O} \text{ (AlCl}_3 \text{for recycling of Al or byproduct)}\]

\[2\text{Al} + 6\text{H}_2\text{O} + 2\text{AlCl}_3 = 4\text{AlCl}_3 + 3\text{H}_2 + Q \text{ (AlCl}_3 \text{for recycling of Al or byproduct)}\]

\[\text{AlCl}_3 + 3\text{KOH} = \text{Al(OH)}_3 + 3\text{KCl} \text{ and then:}\]

\[(2\text{Al}(\text{OH})_3 + Q = \text{Al}_2\text{O}_3(\text{alpha}) + Q = \text{Al}_2\text{O}_3(\text{gamma}) \text{ that may be a byproduct for sale.}\]

\[\text{Al}_2\text{O}_3 + 3\text{CaH}_2 = 2\text{Al} + 3\text{CaO} + 3\text{H}_2 + Q \text{ (exothermic reaction with release of additional energy).}\]

\[(3\text{Ca} + \text{CH}_4 = 2\text{CaH}_2 + \text{CaC})\]
CaC₂ + H₂O = Ca(OH)₂ + C₂H₂

3A1 + 4H₂O + Ca(OH)₃ = Ca (Al(OH)₃) + 4H₂

Ca (Al(OH)₃ + C0₂ = CaC0₃ + Al(OH)₃

Al(OH)₃ ----> A₁₂O₃

As noted above, in one embodiment recycling takes place using the following process:

A1Cl₃ + Q (192°C) heat generated from sediment reaction (salt mix)

A1Cl₃ + electrolysis = Al + 3Cl

A₁₂O₃ + 3CaCl = A₁₂Cl₃ + 3CaO ( CaO + H₂O = Ca(OH)₂ + CO = CaC0₃ + H₂ )

that provides for additional hydrogen production.

A1Cl₃ + 3K (K₂C0₃; KNO₃) = Al + 3KCl

2A1Cl₃ + 3Ca = 3CaCl₂ + 2Al

A1Cl₃ + Fe = FeCl₃ + Al

that is a reaction in liquid ammonia

A₁₂O₃ + 3CaH₂ = 2Al + 3CaO + 3H₂ and (2Al + 6H₂O = 2Al(OH)₃ + 3H₂ and hence this provides for yet additional hydrogen production).

4Al(OH)₃ + 3CH₄ = A1₄C₃ + 12H₂O

3SiO₂ + A1₄C₃ = 2(A₁₂O₃) + 3Si + 3C
2Al(OH)₃ + CH₄ = 2Al + CO + 3H₂

for even more production of hydrogen

Al₂O₃ + 3CaH₂ = 2Al + 3CaO + 3H₂

for even more production of hydrogen

A person of ordinary skill in the art would readily appreciate that the process provide for the obtaining of super-pure materials in particular aluminum oxide Al₂O₃, aluminum hydroxide Al(OH)₃, Aluminum Chloride AlCl₃.

Various embodiments of the invention, in particular the controller 190 thereof, are implemented as hardware, firmware, software, or any combination thereof. Moreover, the software is preferably implemented as an application program tangibly embodied on a program storage unit or computer readable medium consisting of parts, or of certain devices and/or a combination of devices. The application program may be uploaded to, and executed by, a machine comprising any suitable architecture. Preferably, the machine is implemented on a computer platform having hardware such as one or more central processing units ("CPUs"), a memory, and input/output interfaces. The computer platform may also include an operating system and microinstruction code. The various processes and functions described herein may be either part of the microinstruction code or part of the application program, or any combination thereof, which may be executed by a CPU, whether or not such computer or processor is explicitly shown. In addition, various other peripheral units may be connected to the computer platform such as an additional data storage unit and a printing unit. Furthermore, a non-transitory computer readable medium is any computer readable medium except for a transitory propagating signal.
All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future, i.e., any elements developed that perform the same function, regardless of structure.
What is claimed is:

1. An apparatus for manufacturing of hydrogen comprising:
   a reactor;
   a first source for supplying water;
   a second source for supplying an enhancer;
   a third source for supplying scrap aluminum; and
   a controller for controlling at least the supply of the water from the first source, the enhancer from the second source and the scrap aluminum from the third source into the reactor;
   wherein as a result of the presence of the water, the enhancer and the scrap aluminum in the reactor a hydrogen rich atmosphere is released.

2. The apparatus of claim 1, further comprising:
   a first delivery mechanism to deliver the water into the reactor under the control of the controller.

3. The apparatus of claim 1, further comprising:
   a second delivery mechanism to deliver the enhancer into the reactor under the control of the controller.

4. The apparatus of claim 1, further comprising:
   a third delivery mechanism to deliver the scrap aluminum into the reactor under the control of the controller.
5. The apparatus of claim 1, further comprising:
a mixer to mix, under the control of the controller, the water and the enhancer prior
to adding the resultant mixture into the reactor.

6. The apparatus of claim 1, wherein the water is one of: tap water, saline
water, sea water.

7. The apparatus of claim 1, wherein the enhancer is one of: NaOH,
\text{AlCl}_3, \text{X6H}_2\text{O}, \text{H}_2\text{SO}_4, \text{Al}_2\text{SO}_4, \text{KOH}, \text{Ca(OH)}_2.

8. The apparatus of claim 7, further comprising a recycling of the \text{AlCl}_3
enhancer in the reactor when using \text{AlCl}_3 as the enhancer.

9. The apparatus of claim 7, wherein an \text{Al}_2\text{O}_3 byproduct is produced in the
reactor when using NaOH as an enhancer.

10. The apparatus of claim 1, further comprising:
a condensation chamber coupled to the reactor for extracting vapors from the
hydrogen rich atmosphere released from the reactor;
a filter for filtering the hydrogen rich atmosphere released from the condensation
chamber; and
a storage coupled to the filter for storing the hydrogen.

11. The apparatus of claim 10, wherein the filter comprises at least one of:
a chemical filter to adsorb unwanted gasses from the hydrogen atmosphere; or
12. The apparatus of claim 1, further comprising:
   a cooler that cools the reactor.

13. A method of manufacture of hydrogen comprising:
   mixing scrap aluminum in a solid phase, water and an enhancer in a reactor;
   collecting a hydrogen rich atmosphere generated in the reactor;
   removing vapors from the collected hydrogen rich atmosphere in a condensation
   chamber;
   filtering the hydrogen rich atmosphere; and
   storing the hydrogen outputted from the filters in a hydrogen storage.

14. The method of claim 13, wherein the water and the enhancer are mixed to
   form a solution prior to mixing the solution with the scrap aluminum in the reactor.

15. The method of claim 13, wherein the water is one of: tap water, saline water,
   sea water.

16. The method of claim 13, wherein the enhancer is one of: NaOH,
   AICl3X6H2O, H2SO4, AI2SO4, KOH, Ca(OH)2.

17. The method of claim 16, further comprising:
   recycling of the AICl3 enhancer in the reactor when using AICl3 as the enhancer.

18. The method of claim 16, further comprising:
   a mechanical filter for removal of unwanted particles from the hydrogen
   atmosphere.
removing an $\text{Al}_2\text{O}_3$ byproduct produced in the reactor when using NaOH as an enhancer.
19. The method of claim 13, further comprising:

cooling the reactor.
FIGURE 2
START

S310 Mix Aluminum scraps, water and an enhancer in a reactor

S320 Collect Hydrogen rich atmosphere from the reactor

S330 Remove vapors from the collected Hydrogen rich atmosphere

S340 Filter the de-vaporized Hydrogen rich atmosphere

S350 Store the filtered Hydrogen rich atmosphere

END

FIGURE 3
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC (2013.01) COIB 3/08, BOl J 7/02, BOl J 8/00, COIF 7/42, COIF 7/56, COID 1/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC (2013.01) COIB, BO1J, COIF, COlD

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database consulted during the international search (name of database and, where practicable, search terms used)

Databases consulted: THOMSON INNOVATION, Google Patents


C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Date of the actual completion of the international search 04 Aug 2013
Date of mailing of the international search report 05 Aug 2013

Name and mailing address of the ISA:
Israel Patent Office
Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel
Facsimile No. 972-2-5651616

Authorized officer
ZAKHARIA Imad
Telephone No. 972-2-5651686

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## INTERNATIONAL SEARCH REPORT

**Information on patent family members**

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