Review of Recent advanced in solar thermo-chemical reactors for hydrogen production from water

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***Abstract*— In this paper a review of solar thermo-chemical reactors for hydrogen production from water is presented.**

***Keywords*— Thermochemical, Water, Solar, Hydrogen, Reactor**

I. INTRODUCTION

By the next 40 years even the most conservative scientists estimates that energetic requirements in the world will increase more than 100 %, brings a continued increased use of conventional petroleum- based fuels to satisfy the worldwide increase in energy demand , it leads to an unacceptable environmental consequences with the increased concentrations of greenhouse gas that causes global warming. We actually eject around 25.10^9 ton yearly and the ecosystem can recycle $4-7.10^9$ ton of CO_2 yearly, and. additionally, energy savings rates in developed economies have slowed since 1990, as has the decline in CO_2 emissions relative to GDP. But in general the emission of greenhouse gas CO_2 will still grow to 32.10^9 ton per year by the 20 next years, mostly from power fuels for transportation and stations generating electricity power. As a result, many people in 3th word, mainly in Africa, face an increasing risk of, water shortages, flooding, desertification, and severe environmental pollutions that are expected to cause about 150,000 additional deaths yearly. [1, 2]

Currently it is necessary to think how we can reduce carbon emissions from fossil fuel combustion several fold within this century. This current energetic circumstance, with ecological problems, and the run out of fossil fuels, precise new energy production technologies [3] .

The sun is our largest and cheapest energy resource available, it could be considered the ultimate renewable energy resource. It unceasingly bombards our planet with energy, with approximately 60 minute of solar energy equating to more than all of the world annual energy consumption [4] the solar energy reserve is essentially unlimited. No one owns it. And its use hasn't effect on ecological system . Good enough reasons to expect increasing utilization of solar energy, if it were not for the following very serious drawbacks: solar radiation reaching the earth is very dilute (only about 1 kW per square meter), intermittent (available only during day-time), and unequally distributed over the surface of the earth (generally between 30° north and south latitude). The main challenge is how can we get hold of solar energy such that it can be stored and transported from the sunny and unpopulated regions of the earth's sunbelt to populated centers and industrial area outside the earth's sunbelt, where much of the energy is required? [5] Currently, green hydrogen production from green energy is becoming a very important aspect to take into account inside the real launch of this gas as a new clean alternative energy carrier. The world demand more and more a "sustainable development", bearing in mind that hydrogen production technologies can be or not clean technologies depending on their sources and proceedings followed. Hydrogen production from renewable energies is becoming more prominent [3] The harnessing of the huge renewable energy potential like solar radiation and its effective conversion to fuel is becoming the first challenge for scientists.

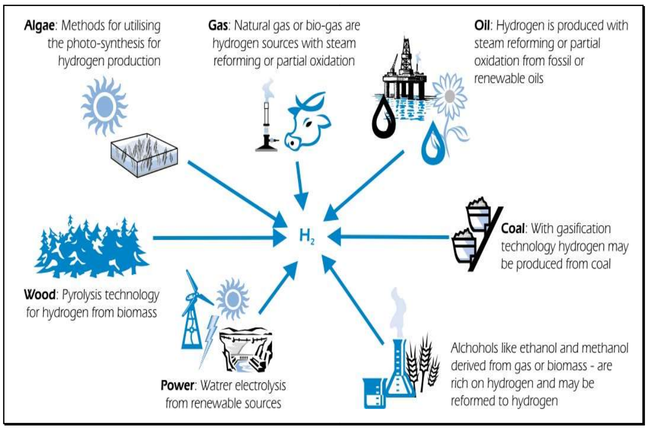

Fig. 1 Hydrogen production proceedings [7]

Actually, prodigious efforts are focused worldwide on the conversion of solar radiation into "green fuels" with hydrogen

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being among the greatest candidates and water H_2O being the raw material. [8]. There is two processes to produce hydrogen from water:

Water electrolysis using solar electricity produced by photovoltaic array , this process is technically doable, but economically it is not yet feasible [9]. Direct solar water splitting. The second promising processes is the direct one-step water splitting (Thermolysis) ,this process requires a very high temperature > 2200 C

A great efforts are done by researchers to reduce the high temperature value, by using thermochemical cycles. thermochemical water splitting cycles present the most promising techniques for achieving thermic water decomposition at low temperature .

II. BACKGROUND

A. Water Thermochemical Solar hydrogen production

The solar thermochemical water splitting is a series of intermediate reactions, which are mainly thermally driven .This process has many advantages relative to processes. In particular, the process is often seen as a competitor to water electrolysis. As an example, net electrolysis efficiencies are around 24%, whereas for the thermochemical hydrogen production using thermal nuclear energy the net efficiencies can up to 50% [10].

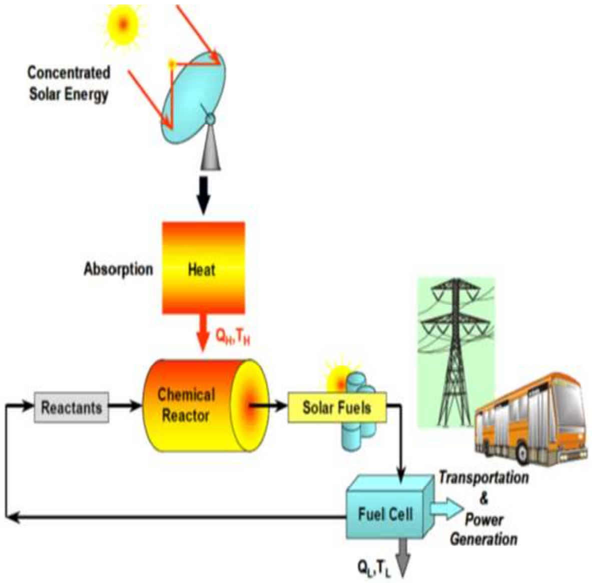

Fig. 2 Thermochemical hydrogen production cycle [11]

It is well known that thermal nuclear energy can be a primary energy source for water decomposition via thermochemical cycles, many cycles are reviewed to be coupled with a nuclear reactor [12].

Thermochemical cycles need a high temperature, this criteria is available just for thermal solar energy field, An interesting solar thermochemical cycles database was developed by Robert Perret for Sandia National Laboratories [13] , and other interesting developed by PROMES laboratory [14] . Around 200 thermochemical cycles have been reported, but the technical status of many of them is at the experimental or bench-scale stage. The main reason for this is the technical problems to be solved before commercialization, such as the separation of products and the circulating agent and equipment development for industrialization. In addition, thermochemical reactions may cause pollution problems if the process is not completely closed [15]. One major class of TWSC that fits in the range of temperatures provided by tower and dish-type solar concentrators are the two-step cycles involving metal (M) oxides [16]:

$$M_xO_y \rightarrow xM + (y/2)O_2 \text{ (endothermic)}$$

$$xM + yH_2O \rightarrow M_xO_y + yH_2 \text{ (exothermic or thermo-neutral)}$$

Here, MxOy denotes a metal oxide, and M the corresponding metal or lower-valence metal oxide. In the first, endothermic, solar step, MxOy is thermally dissociated into the metal or lower-valence metal oxide M and oxygen. Concentrated solar radiation is the energy source for the required high-temperature process heat. In the second, exothermic, non-solar step, M reacts with water to produce hydrogen. The resulting metal oxide is then recycled back to the first step [17]

III. SOLAR THERMOCHEMICAL REACTORS :

A. Volumetric reactors

Porous ceramic foams are used to achieve high performances in the solar heat recovery systems. Predictions of heat transfer between the air flow and the ceramic foam is of great importance when optimizing the volumetric air receiver. In this study, fluid flow and convective heat transfer of air in ceramic foams were numerically investigated. Many developed reactor are based on this technology [18], the main are HYDROSOL 1 and 2, The aim in this projects is to combine a monolithic honeycomb support structure capable of achieving high temperatures when heated by concentrated solar radiation, with a redox pair system suitable for the performance of water dissociation and for regeneration at a specific temperatures [19].

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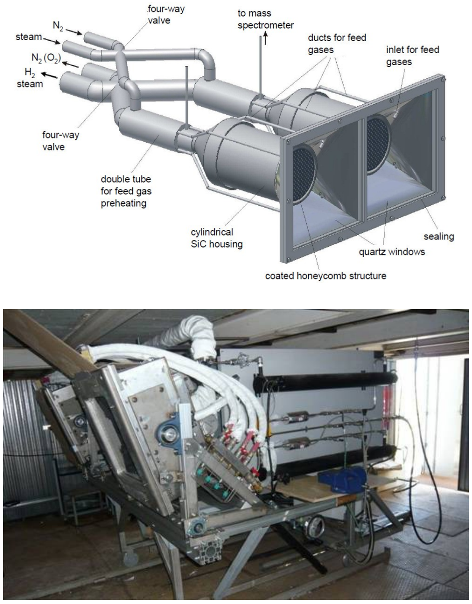

Fig. 3 Hydrosol 2 reactor

A 1 kW thermochemical solar reactor/receiver is also tested at PROMES laboratory is based on the same reactor philosophy [20].

B. Fluid bed reactors

The reactor concept, as shown in Fig. 4, is based on direct solar irradiation of either "suspension of reacting particles in a gas stream" or "falling particles", providing efficient heat transfer directly to a large mass of reacting particles . This reactor concept was experimentally demonstrated using two kinds of laboratory-scale reactors: a "quartz tube" reactor and a "windowed stainless tube" reactor .

In these systems, the ferrite particles are always transported upwards in the draft tube and move downwards in the annulus section. This particle circulation within the reactor enables solar energy transferring from the top of the fluidized bed to the bottom, because directly solar-irradiated particles in the top region always move to the bottom region. This creates a more uniform temperature distribution throughout the internally solar-irradiated fluidized bed, when compared with a conventional solar-irradiated fluidized bed [21].

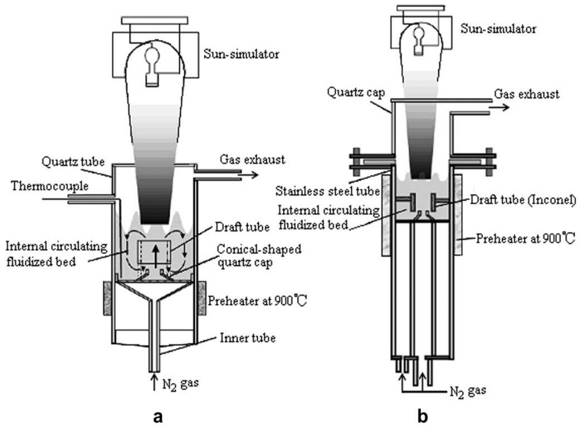

Fig 4 . Fluid bed reactor

C. Rotator reactors

The main experimental study in this field was done by PSI's solar furnace, a 10-kW solar chemical reactor directly exposed to concentrated solar radiation , Solar reactor: The 10-kW solar reactor prototype is shown in Fig. 5.

It has been previously described in detail (Müller,2005); only the main features will be highlighted here. Its main component is a rotating cylindrical cavity (#1) that contains a 6-cm diameter aperture (#2) to let in concentrated solar radiation through a 3-mm thick quartz window (#3). The cavity is built from Hf/HfO2 and packed within ceramic insulation (#6). The reactor has a dynamic ZnO feeding system (#7) that extends and contracts within the cavity, and enables to evenly spread out a layer of ZnO along the entire cavity that is held by centripetal acceleration. The window is protected from condensable gases by injecting Ar through tangential and radial nozzles. Ar is further used to carry the gaseous products Zn(g) and O2 to the quench unit that is integrated in the axial feeding system (Fig. 5, right).

In the quench zone, the product gases flow along the water-cooled annular gap (#7), and finally exit through the rear of the reactor (#8). The cold walls and the injection of additional Ar at ambient temperature promote the rapid cooling of the product gases [22].

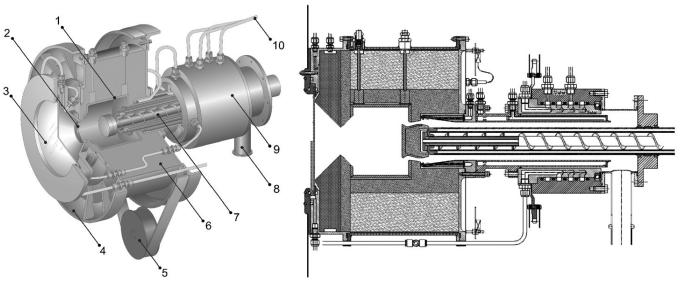

Fig 5. Rotary reactor (ZIRRUS)

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IV. CONCLUSIONS

There is many deferent configuration of solar thermochemical reactor, a few were developed and test successfully, in general there is tree type of solar hydrogen reactors (volumetric, fluid bed and rotary reactors) the main promising is the volumetric based on porous medium , taking in account that the latter is the easiest technically and it has the lowest operating temperature with a high efficiency value.

REFERENCES

[1] Harnessing Solar Energy for the Production of Clean Fuels. PDF. http://www.esf.org/fileadmin/Public_documents/Publications/CleanSolarFuel_01.pdf

[2] Omar Behar , Abdallah Khellaf , Kamal Mohammedia., A review of studies on central Receiver Solar thermal power plants, Renewable and Sustainable Energy Reviews 23(2013)12–39

[3] M. A.Suárez-González,A.M. Blanco-Marigorta, andJ. A.Peña-Quintana, *Review on hydrogen production technologies from solar energy*, International Conference on Renewable Energies and Power Quality (ICREPQ'11) Las Palmas de Gran Canaria (Spain), 13th to 15th April, 2011

[4] Samuel S.Mao , Shaohua Shena,, LiejinGuob, Nanomaterials for renewable hydrogen production ,storage ," *Progress inNaturalScience:MaterialsInternational2012;22(6):522–534*.

[5] Aldo Steinfeld, Robert Palumbo, "SOLAR THERMOCHEMICAL PROCESS TECHNOLOGY," ENCYCLOPEDIA OF PHYSICAL SCIENCE & TECHNOLOGY R. A. Meyers Ed., Academic Press, Vol. 15, pp. 237-256, 2001..

[6] M. A.Suárez-González,A.M. Blanco-Marigorta, andJ. A.Peña-Quintana, Review on hydrogen production technologies from solar energy, International Conference on Renewable Energies and Power Quality (ICREPQ'11) Las Palmas de Gran Canaria (Spain), 13th to 15th April, 2011

[7] HYDROGEN PRODUCTION AND STORAGE. HYDROGEN IMPLEMENTING AGREEMENT *INTERNATIONAL ENERGY AGENCY 2006*

[8] M. Kostoglou, C.P. Lekkos, .G. Konstandopoulos, "On mathematical modeling of solar hydrogen production in monolithic reactors" Computers and Chemical Engineering 35 (2011) 1915– 1922

[9] Djamal DARFILAL, Chakib SELADJI, Youssouf FRAINE, "Conception et simulation d'un système de production d'hydrogène par électrolyse EHT (application au site d'Adrar 16èmes Journées Internationales de Thermique (JITH 2013) Marrakech (Maroc), du 13 au 15 Novembre, 2013.

[10] Marc A. Rosen, "Developments in the production of hydrogen by thermochemical water decomposition," International Journal of Energy and Environmental Engineering ISSN: 2008-9163 Vol.2 / No.2 (pp.1-20) / Spring 2011.

[11] Anton Meier and Aldo Steinfeld, " Solar Thermochemical Production Advances'' in Science and Technology Vol. 74 (2010) pp 303-312of Fuels

[12] Tatsuya Kodama and Nobuyuki Gokon.'' Thermochemical Cycles for High-Temperature Solar Hydrogen Production''Chem. Rev. 2007, 107, 4048-4077

[13] Robert Perret '' Solar Thermochemical Hydrogen Production Research (STCH)'' SAND2011-3622 Unlimited Release Printed May 2011

[14][14]

[15][15]

[16] Tasneem Abbasi, S.A. Abbasi"Renewable' hydrogen: Prospects and challenges"Renewable and Sustainable Energy Reviews 15 (2011) 3034– 3040

[17] Aldo Steinfeld and Alan W. Weimer''Thermochemical Production of Fuels with Concentrated Solar Energy''26 April 2010 / Vol. 18, No. S1 / OPTICS EXPRESS A100

[18] Zhiyong WU, Cyril CALIOT, Fengwu BAI, Gilles FLAMANT, Zhifeng WANG '' Numerical study of interfacial heat transfer between air flow and ceramic foams for optimizing volumetric solar air receiver

[19] C. Agra otis, A.G. Konstandopoulos, S. Lorentzou, C. Pagkoura, A. Zygogianni, M.Roeb, J.-P. Säck, P. Rietbrock, C. Prahl, H. Schreiber, M. Neises, M. Ebert, W. Reinalter,M. Meyer-Grünefeld, C. Sattler, A. Lopez, A. Vidal, A. Elsberg, P. Stobbe, D. Jones,A. SteeleDemonstration of Solar Hydrogen Production fromWater Splitting via Monolithic Honeycomb Reactors in a 100-kW-Scale Pilot Plant '' 18th World Hydrogen Energy Conference 2010 - WHEC 2010

[20] H.I. Villafán-Vidales a, Stéphane Abanades a,*, Cyril Caliot a, H. Romero-Paredes''Heat transfer simulation in a thermochemical solar reactor based on a volumetric porous receiver''Applied Thermal Engineering 31 (2011) 3377e3386

[21] Lan Xiao a,b, Shuang-Ying Wu a,b,*, You-Rong Li''Advances in solar hydrogen production via two-step water-splitting thermochemical cycles based on metal redox reactions''Renewable Energy 41 (2012) 1e12

[22] R. Müllera, A. Steinfelda, H2O-splitting thermochemical cycle based on ZnO/Zn-redox: Quenching the effluents from the ZnO dissociation''Chemical Engineering Science 63 (2008) 217 –