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"Solar Hydrogen"

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SOLAR HYDROGEN

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ABSTRACT

Search for an efficient and clean fuel, in the context of rapidly degrading environment, is one of the momentous tasks facing mankind. Hydrogen seems to come out as the most appropriate and a highly potential fuel in this search. It is the lightest and cleanest amongst all the fuels. It can be produced by four main methods: direct thermal, thermochemical, electrolysis and photolysis. Amongst these, water electrolysis is the best known and the simplest method for producing hydrogen, either on a small scale or a large scale.

Environmental considerations require that hydrogen is to be produced from nonfossil energy sources. Solar photovoltaic-electrolyzer system answers this requirement very eminently. One such research and demonstration system, which is on a fairly large scale, was established at the Solar Village near Riyadh, under the German-Saudi technical cooperation program, where the author worked with the scientific group there. The essential features of the system and its relevance to developing nations are presented in the paper.

INTRODUCTION

Environmental Degradation

There are several crucial issues that mankind is currently facing. Three of them seem to be the most critical to the developing nations, in particular. They are population explosion, energy shortage and environmental damage. The last one is strongly related to the topic of this paper and hence a brief discussion is made here.

All conventional energy sources generate pollution. Fossil fuel combustion products enter into atmospheric reactions and produce enormous amounts of carcinogenic organic compounds, which are highly detrimental to human health. Pollution damage, particularly from automobiles, is high even in developing nations like India, where automobile population is relatively small. Every day motor vehicles spew thousands of tonnes of pollutants into the atmosphere. In Bombay, for example, a 1991 study showed that motor vehicles account for about 93 percent of the carbon monoxide, 73 percent of the nitrogen oxides, and 99 percent of the hydrocarbon emissions in the air that the residents breathe[1]. Carbon monoxide is fatal in high concentrations. Also, atmospheric carbon dioxide is getting to be a formidable environmental problem due to the so-called 'green house effect'. Earth's temperature has begun to rise at an increasing rate with consequent disastrous effects. Acid rain kills fish in the lakes and ponds and reduces agricultural and timber harvests. Prof.Veziroglu, Director of the Clean Energy Research Institute at Miami, Florida, says,"....

when we consider all the detrimental effects and limitations of petroleum and other fossil fuels, one begins to think that we are fortunate to be running out of them. If there were an interminable supply of fossil fuels, we would eventually turn this planet into a desolate graveyard."[2]

What has been said above emphasizes the fact that mankind badly needs a clean and efficient fuel. Hydrogen seems to answer this need in an abundant measure. Also, hydrogen is the most plentiful element in the universe, and has the most desirable properties of a fuel.

Production of Hydrogen

The most abundant feed-stocks for hydrogen production are water, coal, oil and natural gas. Hydrocarbons can be reformed, cracked, oxidized or gasified to produce hydrogen. Hydrogen can also be produced from biomass.

Water can be decomposed by thermal and thermochemical methods.

$$2H_2O \longrightarrow 2H_2 + O_2$$

Thermal decomposition is highly energy intensive, and thermochemical method, wherein the sum of several reaction sequences leads to the decomposition of water has serious problems concerning reaction rates, separation of products, etc. Researchers are of the opinion that thermal and thermochemical approaches should be discarded and efforts focused on photovoltaic schemes [3]. Also, environmental considerations would weigh very heavily against the use of fossil fuels for hydrogen production.

Water can be split into its constituent elements, hydrogen and oxygen, by photolysis or electrolysis. Attempts to produce hydrogen directly by the photolysis of water or by the use of chlorophyll in a modified scheme of photosynthesis have shown some promise, but these methods are very inefficient and expensive. Splitting of water electrolytically has proven to be the best and the simplest method for producing hydrogen. But the electrical energy required to split the water should come from renewable energy sources such as wind, sun, ocean thermal, etc. Solar energy seems to be the most appropriate amongst all the renewable energy sources, and photovoltaic-powered electrolysis is considered to be the best approach to hydrogen production.

Future Energy Technology

The role of hydrogen in future energy technology will be of great importance to mankind. It will be an indispensable alternative to conventional fuels. Its potential as a clean fuel in road vehicles, its use in rocket engines and jet engines, its suitability for producing electricity in fuel cells, and in a variety of other applications is well recognized. The German Aerospace Establishment is pursuing a vigorous and an imaginative approach to use hydrogen in several applications which include steady and unsteady combustion devices, storage of hydrogen, production of high temperature steam, fuel cells, etc. Similar work is in progress in a few other developed countries. In India, the Department of Non-Conventional Energy Sources has currently 23 projects, which focus on techniques of hydrogen production, system design and development, and storage [4]. These projects are entrusted to a few university laboratories and Indian Instutes of Technology. One research group is working on the production of hydrogen by photoelectrochemical method and its use as a fuel in a motorcycle. Another research group is focusing its efforts in developing an energy-efficient hydrogen engine.

Some Salient Characteristics of Hydrogen

Hydrogen is the lightest of all gases weighing only about one-fourteenth as much as an equal volume of air. It liquifies at about 20 K and 2 bar. On a weight basis hydrogen has 2.4 times as much heat of combustion as that of methane. It can be stored by hydriding metals or alloys. The metals used in hydrides are iron, magnesium, nickel, manganese and titanium. Stoichiometric composition with air is 29.3 percent by volume. Flammable limit with air ranges from 4 to 75 percent by volume. Flame temperature in air is 2045 deg.C. It has a low flame luminocity. It has a much higher normal burning velocity than that of methane or propane. Analyses of physical and chemical properties of hydrogen reveal that hydrogen as a fuel is not as hazardous as one would presume.

SOLAR VILLAGE PROJECT

German-Saudi Technical Cooperation

An excellent research and development project on solar hydrogen production and utilization was established at the Solar Village near Riyadh in 1986. It is a cooperative endeavour between the universities and research establishments of Germany and Saudi Arabia. The author was privileged to work with the scientific group of the project, and he presents here some of the salient and unique features of the project, which could serve as a model to many of the developing nations, endowed with rich sunshine, technical expertise and a determined will to combat pollution that is threatening the health of the entire population. The author has drawn on published material and it is to be noted that he cannot provide classified information on a new product developed by a company andon certain matters that concern the bilateral agreement between research partners.

The Kingdom of Saudi Arabia, though rich in its oil resources, is deeply aware of the role of hydrogen in the emerging technologies and of its paramount importance in protecting our environment. Saudi Arabia is blessed with abundant sunshine, and plenty of land area. The solar power collected at only 10 percent efficiency, on an area of approximately 10,000 square kilometers, is equal to the power equivalent of Saudi Arabia's petroleum production at the current rate [5]. There are two regions that are potentially large-scale solar energy production areas: the northwestern Arabian desert and the Nedschd desert. A big highway from Riyadh to Jeddah runs through this region, and the distance to the Red Sea is only 450 km. The mean daily requirement of water for a solar hydrogen plant, in terms of land area, is about 60 cubic meters per square kilometer per day. In some locations such amounts could be drawn from ground water. It is to be noted that in the Saudi Arabian capital,Riyadh, water supply is guaranteed by bringing in desalinated sea water from the Arabian Gulf through a 466 km long pipeline every day. This shows that enough water is available for hydrogen production [6].

Solar-Powered Electrolytic Plant

The plant comprising of a 350 KW photovoltaic power system and an alkaline electrolyzer is envisioned as a reliable autonomous supply source for hydrogen in remote settlements. The PV power system was established in 1981 to supply electricity to a couple of neighbouring villages. When conventional electricity was made available to the villages, the PV power system was connected to the local grid. The power system has shown excellent results and an impressive performance reliability. The PV-array field comprises of 160 arrays (2 axes-tracked), each array having 64 modules, and each module having 4 cells. The solar cells are made of monocrystalline silicon, and are equipped with fresnel lenses to concentrate solar radiation. The arrays are automatically tracked, and the total aperture area is 3947.5 m^2. Annual data collected for 1985 shows that the captured solar radiation during all the operation hours of the year was 7229 MWh and the corresponding invertor output 588 MWh yielding an overall efficiency of 8.1 percent.

Alkaline Water Electrolysis

Electrolytic dissociation of water can be brought by using alkaline water, solid polymer electrolyte or steam. The first two have found practice in the present commercial technology, and steam electrolysis is yet to achieve its technical maturity [7]. The technology of alkaline water electrolysis with advanced electrolytic cells has made significant progress in terms of improvements in the energy efficiency of hydrogen production, life time, new diaphragm materials withstanding elevated temperatures, and new electrodes. Increasing the working temperature to 100-120 deg.C causes a decrease in electrode over-voltage and also a decrease in ohmic losses throughout the cell. Under such condition commonly used asbestos diaphragm is nolonger stable. Therefore development of new separator is necessary. It should also allow 'zero gap' construction of electrolytic cell.

A new alkaline bipolar electrolyzer, designed to match the 350 kW PV system was supplied by a Belgian company (Hydrogen Systems n.v./s.a., Jan van Rijswijcklaan 17, B-2018 Antwerpen, Belgium). The operation of the electrolyzer under varying power inputs is one of the challenging aspects of the system. After extensive simulation studies, the system is carefully rated to match the characteristics of the PV generator.

The electrolyzer cell block configuration comprises of 144 cells in series, asbestos-free diaphragm, high temperature (100 deg.C) operation, and zero-gap arrangement. The system is built on modular concept with minimal current losses. Combined action of the system control loops and computer programmed sequence assures automatic and stable operation. Rated production of hydrogen is 70 Nm^3/h with an overall efficiency of 7 percent [8].

HYDROGEN UTILIZATION PROGRAM

This program is intended to demonstrate that solar hydrogen technologies are safe, reliable, and environmentally beneficial. A new laboratory building was constructed adjacent to the main building which houses the electrolyzer. The equipment that are installed in the laboratory include a hydrogen-fuelled spark ignition engine, catalytic heater for hydrogen combustion, modified hydrogen-gas lamps, hydrogen-fuelled thermoelectric generator, and a hydrogen-oxygen steam generator. The laboratory, though modest in its current equipment, is expected to enlarge its scope, and attract industries and manufacturers both in Germany and Saudi Arabia to participate in a more comprehensive development program [9].

CONCLUSION

Jule Verne's prophesy in 1847 that water will be employed as a fuel and that hydrogen will furnish an inexhaustible source of heat and light, seems to come true more sooner than we thought. Successful application of hydrogen in space programs, automobiles, fuel cells, etc., has revived a great deal of interest. Sooner or later hydrogen has to be produced on a large scale from nonfossil energy sources. Production of hydrogen by solar PV-powered electrolysis holds out great promise.

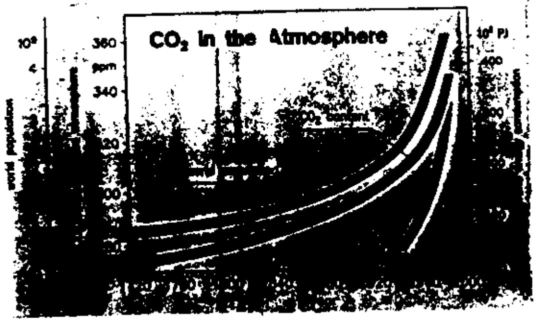

FIGURE 1. CO_2, Population, and Energy Consumption : The concentration of CO_2 in the atmosphere, world population, and world energy consumption are increasing at a phenomenal rate.

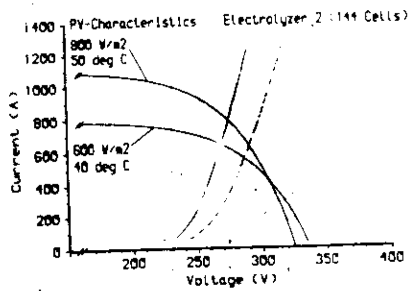

FIGURE 2. Matching of PV and Electrolyzer Systems : The electrolysis system must be carefully rated to match the varying current-voltage characteristics of the PV generator.

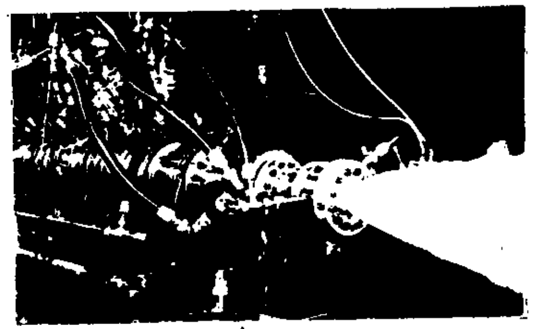

FIGURE 3. DFVLR's Prototype Hydrogen-Oxygen Steam Generator : Rated thermal steam power ranges up to 65 MW. Temperature is controlled by water injection. Thermal efficiency is almost 100 percent.

[Figures through the courtesy of DFVLR]

The Solar Village project is an excellent example of technical cooperation between two countries, aimed to demonstrate advanced solar technologies. The successful integration of two technologies - solar photovoltaic power generation and advanced alkaline water electrolysis - in the project is a fore-runner to several new concepts in hydrogen production technology.

In a country like India, where bulk of the population lives in villages, decentralized electrical power stations would be an asset. Hydrogen can be transported more economically than electricity. It can be used in fuel cells, where it can be efficiently turned into electricity in decentralized facilities.

The author left the Solar Village in the early part of 1990 to continue teaching at Bradley University in USA. At that time, the electrolyzer supplied by the Belgian company was about to be commissioned. However, the author is not aware of further developments at the village site, but wishes the program great success.

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