THE HYDROGEN PRODUCTION BY ELECTROLYSIS OF WATER USING ELECTRIC ENERGY FROM PHOTOVOLTAIC SOLAR MODULE

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Abstract

The carbon dioxide emission from fossil fuels and depletion of fossil fuels sources; the energy economy at present time is directed to renewable energy production with hydrogen production by water electrolyses. This paper presents production of hydrogen, from water by electrolysis using electric energy from photovoltaic solar module, as an environmentally friendly synthetic fuel for many applications.

Key words: hydrogen, fuel, photovoltaic, electrolysis

Introduction

Fossil fuels, particularly oil and natural gas, which presently provide most of our energy sources, are rapidly being depleted. Coal has been less rapidly utilized because it is less convenient because creates the environmental problems with carbon dioxide emission. Figure 1 shows the life of the World minerals and fossil fuels resources. The fossil fuels such as oil natural gas and uranium are shorter than human life as is shown in Figure 1.

Figure 1. Estimated life of the World mineral and fossil fuels resources [1]
Another problem to using the fossil fuels is carbon dioxide production, which make environmental problem [2]. The carbon dioxide emission from different sector of human activity is presented in Figure 2. Because the main emission of carbon dioxide is from energy production, as is illustrated in Figure 2, and the fossil fuels become scarce (Figure 1) the renewable energy production is the best alternative for future energy economy.

![Figure 2. CO$_2$ emission from different sector of human activity](image)

A different type of renewable sources of energy is available but to store the abundant energy will be a critical element for this new renewable energy economy. One possible way to store abundant energy is the hydrogen production by water electrolysis. Hydrogen is an energy carrier suitable as an environmentally friendly synthetic fuel for many applications. The production and utilization of hydrogen in the industry at present time are illustrated in Figure 3 and 4.

![Figure 3. Hydrogen productions](image) ![Figure 4. Hydrogen utilisation](image)

At present time, as is documented in Figure 3, the majority of the world's hydrogen production is from natural gas and the hydrogen utilization is mainly in metallurgical and chemical industry as is illustrated in Figure 4, but in the future the hydrogen production will increase as an energy carrier which will be produced mainly from renewable energy sources. Figure 5 is presented a numerous variable approaches to the hydrogen production from renewable energy sources. One possible way is the electrolyses of water. Water is the largest
source of hydrogen but at present time, as was shown in Figure 3, only 4% of hydrogen is produced via electrolysis of water. This means that for future renewable energy economy the hydrogen production by electrolyses of water must increase but the electric energy for electrolyses must be mainly from solar, wind, hydro and geothermal renewable energy sources as is illustrated in Figure 5.

Figure 5. Hydrogen production from different renewable energy sources

**Conversion of solar energy to electricity**

A photovoltaic cells generating electricity from solar radiation through a potential energy barrier within a semiconductor material that is capable of separating the electrons and holes that are generated by the absorption of light within the semiconductor as is illustrated in Figure 6.

Figure 6. Simplified diagram of solar energy conversion to electricity in photovoltaic solar cell
For construction of solar cells a different types of semiconductor materials are use. The first material for photovoltaic cells construction was silicon single-crystal. The silicon single-crystal photovoltaic cell has become the prototype of all homojunction photovoltaic cells with very high cost per peak watt (a peak watt is the maximum electric energy generated by a cell in the course of an ideal day). After construction of the cuprous sulphide/cadmium sulphide heterojunction thin-film photovoltaic cells the significant attention for construction of these chipper types of photovoltaic cells has been done. Figure 7 is presented the semiconductor materials, which is used for photovoltaic cells production at present time.

![Figure 7. Semiconductor materials for photovoltaic cells production](image)

One of the most important differences between silicon single-crystal and a-Si:H semiconductor materials is the change in the optical absorption spectrum as is shown in Figure 8. The advantage of the a-Si:H semiconductor materials is not only high optical absorption coefficient in the most visible portion of the solar irradiation spectrum but the relatively low cost per peak watt too.

![Figure 8. The optical absorption coefficient for single-crystal Si and a-Si:H](image)
Electrolysis of water

The principal of electrolyses of water in classical electrolyser using alkaline KOH electrolytic solution is schematically illustrated in Figure 9.

![Figure 9. The principal of electrolyses of water](image)

In electrolyser the overall electrochemical reaction take place [6]:

$$\Delta H_{298} = 286.26 \text{ kJ.mol}^{-1} \quad (1)$$

Hydrogen production at the cathode in alkaline electrolyser can be described by reaction:

$$2\text{H}_2\text{O}_{(l)} + 2\text{e}^- = \text{H}_2(g) + 2\text{OH}^- \quad (2)$$

and oxygen production at the anode in alkaline electrolyser by reaction:

$$2\text{OH}^- = 0.5\text{O}_2(g) + 2\text{H}_2\text{O}_{(l)} + 2\text{e}^- \quad (3)$$

For production of hydrogen and oxygen on the cathode and anode located in electrolyser, the minimum potential between the electrodes is needed:

$$U_m = \frac{\Delta H^o_{298}}{nF} = 1.48 \text{ V} \quad (4)$$

New developed technology for electrolyses of water is PEM electrolyses with solid proton exchange membrane [7]. The PEM electrolysers are using pure water and not require the KOH electrolytic solution as classical type of electrolysers. The overall electrochemical reaction in PEM electrolyser is the same as reaction (1), but the hydrogen production at the cathode in PEM electrolyser can be described by reaction:

$$2\text{H}^+ + 2\text{e}^- = \text{H}_2(g) \quad (5)$$

and the oxygen production at the anode in PEM electrolyser by reaction:

$$2\text{H}_2\text{O}_{(l)} = 0.5\text{O}_2(g) + 2\text{H}^+ + 2\text{e}^- \quad (6)$$
The functional principle of a PEM electrolyser is illustrated in Figure 10.

![Figure 10. The functional principle of a PEM electrolyser [7]](image)

**Experimental tests**

For experimental tests of hydrogen production by electrolysis of water via conversion of solar energy on electricity by the photovoltaic amorphous silicon solar module installed in the Department of Power Engineering, illustrated with working parameters in Figure 10, has been used.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power ( P_{\text{max}} )</td>
<td>51 W</td>
</tr>
<tr>
<td>Area of solar module ( S_C )</td>
<td>0.78 m²</td>
</tr>
<tr>
<td>Open-circuit voltage ( U_{\text{OC}} )</td>
<td>25 V</td>
</tr>
<tr>
<td>Short – circuit current ( P_{\text{SC}} )</td>
<td>3.3 A</td>
</tr>
<tr>
<td>Maximum operating voltage ( U_{\text{pmax}} )</td>
<td>17.6 V</td>
</tr>
<tr>
<td>Maximum operating current ( I_{\text{pmax}} )</td>
<td>2.6 A</td>
</tr>
</tbody>
</table>

![Figure 10. Solar module and his working parameters](image)

For hydrogen production has been used PEM electrolyser StaXX7. The block diagram of the connection between solar module, electrolyser and accumulator via solar regulator is shown in Figure 11. The basic data as illumination, temperature and voltage of electricity generating by photovoltaic solar module during day has been monitoring by PC computer. The example of diagram with one-day monitoring data is illustrated in Figure 12.

By this installation the hydrogen and oxygen was produced by electrolyses of water only if the voltage of electric energy generating by photovoltaic solar panel was higher as 10.5 V. If the voltage was much higher as 10.5 V the electrolyses of water ran altogether with the accumulator charging. If the voltage was lover as 10.5 V the electrolyses of water has been ran by power from the accumulator. The volume of hydrogen produced by electrolyses of
water was measured and stored in hydrogen reservoir and oxygen has been emitted into the atmosphere. As hydrogen and oxygen was produced in the electrolyser, water was consumed and must be replaced. For electrolyser Sta XX7 the distillated water has been used.

![Figure 11. Block diagram of experimental installation](image1)

![Figure 12. Diagram with one-day monitoring data](image2)

**Results and discussion**

The current-voltage and power characteristic of the amorphous silicon photovoltaic solar module at constant illumination 98 093 lux has been measured and plot as diagram in Figure 13. From current-voltage characteristic at constant illumination 98 093 lux the maximum power production of the solar module at $I_M = 2$ A and $U_M = 13.71$ V is $P_M = 27.5$ W has been calculated. If the average solar irradiation in Slovakia is $G_T = 580$ W.m$^{-2}$ the solar efficiency for conversion of solar energy to electricity for used solar module can be expressed as:

$$\eta_M = \frac{I_M \cdot U_M}{S_c \cdot G_T} = 6 \%$$

(7)
From approximately linear current-voltage characteristic of PEM electrolyser StaXX7 plotted in Figure 14 the minimum voltage 10.5 V for water electrolyses was determined. The amount of hydrogen production depends on current density. That means that at constant area of electrodes in electrolyser, as is shown in Figure 15, at higher current intensity in electrolyser the production of hydrogen is higher and opposite at lower current intensity the production of hydrogen is lover but if current intensity increasing the efficiency of electrolytic process decreasing as is evident from Figure 16. The efficiency of electrolytic process in PEM electrolyser StaXX7 was relatively high and varied from 0.95 to 0.75.
Figure 16. Efficiency of electrolytic process versus current intensity

The pure hydrogen produced by electrolysis of water, using electric energy from a new renewable sources of energy such as solar energy, wind energy and so on, is a suitable synthetic fuel for many applications. Hydrogen can be used directly for heat production by combustion or via fuel cells for electricity and heat production. In both cases the water is producing as a waste that is showed Figure 17.

Figure 17. Production and utilization of hydrogen

**Conclusions**

Fossil fuels, particularly oil and gas, which presently provide most of our energy sources, are rapidly being depleted. Coal has been less rapidly utilized because creates environmental problems.

To cut carbon dioxide emission a new alternative sources such as solar and wind energy have to be introducing into energy infrastructure.

Using a new alternative sources we must have the ability to store the abundant energy. One possible way to store abundant energy is the hydrogen production by water electrolysis.

When hydrogen is produced through electrolysis of water, the electric energy must come from renewable energy sources.

The hydrogen can be used for energy production by different ways such as combustion or via fuel cells. In both cases the water is producing as a waste.

Hydrogen production by water electrolyses is environmentally friendly technology for energy storage and utilization. This means that hydrogen is the fuel for future.
References

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