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Technologies of PEM Fuel Cells and their application to LED semaphores and lighting systems

José Javier San Martín, José Ignacio San Martín, Víctor Aperribay
Iñigo Javier Oleagordia, Iñaki Martín, and José Mª Arrieta

Abstract**—**The world today suffers the consequences of the use of fossil fuels, their polluting emissions and global warming consistent. All this makes it imperative the search for new energy models, more efficient and less polluting. One of the most promising alternative technology is based on hydrogen as new energy vector or applied to combustion engines or fuel cells. A PEM fuel cell (Proton Exchange Membrane) is a clean electrical and thermal generator, of high efficiency, which is fed with hydrogen and oxygen or air. Its behaviour depends on a high number of parameters, such as: temperature, humidity, pressure, etc. Many of these parameters are related with the supply of gases. In this scenario, this paper presents the results obtained after the analysis and test of a fuel cell. This way, a revision of the most outstanding characteristics in the six modalities of fuel cell is presented. The theoretical study of these devices is carried out and experimental results obtained with a PEM fuel cell are included. This work presents a new multimedia teaching tool aimed at teaching Renewable Energies, trying aspects ranging from storage of surplus renewable energy in the form of hydrogen, until the applications of this kind in PEM fuel cells. The main objective is aware of the need in the use of clean renewable energy, specifically with hydrogen, in a bid to clear the immediate future. All the experiments are based on modules of Ventus FC50 Science, which have made practices, such as study of security measures, curves of a fuel cell, parameters that influence, efficiency of fuel cell stack and finally, implementation of the fuel cell to traffic lights with LED technology, uninterruptible power supplies (UPS), to solve the problem of interruptions in electricity supply and the dangers and risks involved in the movement in these conditions. Also provides for the implementation of fuel cell system in lighting, analyzing the cost of kWh.

Keywords**—**Hydrogen, Fuel Cells, Electrolyser, Inverter, LED Semaphores, Lighting Systems.

I. INTRODUCTION

Because the problems associated with the current energetic model, based in fossil fuels, such as atmospheric contamination and the prizes fluctuations in the market, it is necessary finding renewable energies with no emissions. This is intended to take the first step to install hydrogen technology, so that the society understands and accepts as a new form of clean and efficient energy.

Hydrogen is what we call a vector energy, namely a way to accumulate and distribute energy. Today, most hydrogen is produced, is derived from natural gas. This presents a serious inconvenient because it is a fossil fuel and contains carbon, thus it appears at the end of the process in the form of CO_2, with the consequent increase in atmospheric concentrations of greenhouse gases.

That is why paper is in trying to generate hydrogen from renewable energies non-polluting [1].

An alternative is to obtain hydrogen by electrolysis of water and electricity needed to realize this process is energy from renewable non-polluting, such as wind or solar.

Fuel cells are electrochemical devices that allow chemical energy conversion into electrical power, heating and water. This transformation uses the free energy available directly in the fuel to the operation temperature. Besides, it is not limited by the Carnot cycle, reaching superior efficiencies to conventional process. In this last one, the chemical energy of the fuel transforms, firstly, in thermal energy of a fluid, later on mechanical energy of an axis and, finally, in electrical power. In fuel cells devices, transformation takes place from chemical energy directly to electrical one, in absence of intermediate conversions of thermal or mechanical energy.

In this work is presented a new teaching multimedia tool whose objective is showing this new energetic source and its application in fuel cells.

This multimedia course presents, after an Introduction, a section whose purpose is that the user can arrange the referring theoretical knowledge to hydrogen and fuel cells. The information available in this course deals with depth these subjects, but with the expectation of the assimilation, as much by a novice person, like by a person introduced in the world of hydrogen and fuel cells.

II. PERFORMANCE OF A PEM FUEL CELL

The PEM fuel cell takes its name from a polymer which interchange protons, with low permeability to hydrogen and oxygen. One of the most commercially known materials is the "Nafion" that is based on a polyethylene polymer, manufactured by DuPont. Another company, Dow Chemical,

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All authors are teachers of the Department of Electric Engineering in the University of the Basque Country, Avda. Otaola, 29, 20600 Eibar (Spain) (phone: +34 94 303 3064).

E-mail: iepsmdij@sb.ehu.es.

has its own membrane version "Dow". However, a great effort is being carried out in the partial substitution of the previous material for: other more efficient polymers in the retention of water; hybrid materials; glasses or porous ceramic materials [2]. This substitution would imply an important reduction of the PEMFC and DMFC costs.

Anode and cathode are manufactured of fabric or graphite leaf. They contain particles of very dispersed metallic alloy (most of it platinum, in quantity of 0.32 mg/cm2) that behave as very active catalysts. If the PEM Fuel Cell feeds with hydrogen coming from a reformer, since it contains small quantities of CO, it is necessary to use platinum-rutenio (PtRu) in the anode. In this way, the poisoning with the monoxide of carbon is prevented. The catalytic PtRu tolerates CO concentrations until 100 ppm. The quantity of necessary Pt in each electrode, according to the NASA, is of 0.3 g/m^2.

However, the high price of platinum forces to develop other techniques, so that, the used quantity is smaller. Another solution is to look for another material that can substitute it. Developments, as those carried out by Alamos Laboratory, have demonstrated techniques to reduce the quantity of platinum up to 0,021 g/m2, maintaining the same advantages.

These fuel cells operate to relatively low temperatures (about 80 ºC). This temperature allows starting up quickly because they need less time of heating. Although around 3 minutes are needed to reach the maximum power, they provide 50% of the same one immediately after their ignition. Other characteristics are a high energy density and quick response to demand variations. On the other hand, the low operation temperatures and the solid electrolyte make that the useful life of these fuel cells is near to 50.000 hours. Additionally, the electrical efficiency is about 60%, using pure hydrogen, and 40%, with methane.

In the PEM fuel cell, the anode is fed with hydrogen. There, the oxidation reaction of H_2 takes place, giving place to protons, according to the following equation:

$$2\,H_2 \longrightarrow 4H^+ + 4e^-$$

In other words, the catalyst divides the hydrogen molecule into protons and electrons. The liberated protons are transmitted through the membrane, by means of the diffusion mechanism of jumps of protons, from one to another molecule of water, through the channels of this membrane. The cathode is fed by the oxygen of air and a reaction takes place to the operation temperature of the fuel cell (around 80 ºC). This reaction is the following one, which takes the necessary electrons of the external circuit:

$$O_2 + 4H^+ + 4e^- \longrightarrow 2\,H_2O$$

Being the global expression, the following one:

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

III. THERMODYNAMIC ASPECTS OF FUEL CELLS

To constant temperature and pressure, and under reversible conditions, the fuel oxidation is developed taking maximum advantage of the free energy of Gibbs reaction, ΔG [2]. This magnitude is related thermodynamically with the reaction enthalpy and entropy according to equation (1):

$$\Delta G = \Delta H - T\Delta S \tag{1}$$

Besides,

$$W_{elec} = \Delta G = -nFE \tag{2}$$

where:

n: Number of electrons in the electrochemical reaction (for hydrogen, its value is 2).

Units for Magnetic Properties F: Constant of Faraday 96487 C/mol.

E: Voltage of the basic fuel cell, V.

T: Absolute temperature, K.

The ideal efficiency (thermodynamic efficiency,) of the fuel cell, under reversible conditions, is defined as (3).

$$\eta_t = \frac{\Delta G}{\Delta H} = -\frac{nFE}{\Delta H} \tag{3}$$

and keeping in mind (1), we can write:

$$\eta_t = \frac{\Delta H - T\cdot\Delta S}{\Delta H} = 1 - T\,\frac{\Delta S}{\Delta H} \tag{4}$$

The thermodynamic properties of H_2, O_2 y H_2O are indicated in Table 1, under standard conditions (p = 1 atm = 1,01325 bar y T = 25 ºC = 298 K).

TABLE I
THERMODYNAMIC PROPERTIES

PROPERTIES	**H_2**	**O_2**	**H_2O** (LIQ)	**H_2O** (GAS)
Enthalpy H (kJ/mol)	0	0	-285.83	-241.82
Entropy S (J/mol K)	130.68	205.14	69.91	188.72

Thus, using the numerical values shown in Table 1 and the Hess law, we can obtain the following values:

$$\Delta H = \Delta H_{reaction} = \sum H_{products} - \sum H_{reagents} \tag{5}$$

$$\Delta H = -285.83 \text{ kJ/mol} \tag{6}$$

$$\Delta S = \Delta S_{reaction} = \sum S_{products} - \sum S_{reagents} \tag{7}$$

$$\Delta S = -163.34 \ {}^{\text{J}}\!\!\diagup_{\text{K}\cdot\text{mol}} \tag{8}$$

The heat absorbed by the system will be:

$$\Delta Q = T\cdot\Delta S = -48.7 \text{ kJ/mol} \tag{9}$$

Besides, the free energy of Gibbs can be obtained, according to the equation (2), as follow:

$$\Delta G = \Delta H - T \cdot \Delta S = -237.13 \text{ kJ/mol} \qquad (10)$$

And, using the Gibbs function, we obtain:

$$-\Delta G = W_{elec} = 237.13 \text{ kJ/mol} \qquad (11)$$

Based on the previous calculations, we can confirm that the electrochemical reaction in the fuel cell produces an electrical power of 237.13 kJ/mol and heating of 48.7 kJ/mol.

IV. Fuel cell main parameters

From equation (2), the theoretical output voltage E^0, that corresponds to the hydrogen oxidation in a reversible and isotherm process, can be calculated for a fuel cell with the expression (12), under standard conditions.

$$E^0 = \frac{-\Delta G}{nF} = 1.23 \ V \qquad (12)$$

This theoretical value happens if water is formed in liquid state.

Besides, for example, the PEM fuel cell operates with temperatures around 80 ºC. So, admitting an ideal behaviour of gases, and that the enthalpy and entropy variation of the chemical reaction do not vary significantly with temperature, the value of ΔG can be obtained in accordance with equation (1):

$$\Delta G = \Delta H - T \cdot \Delta S \cong \Delta H^0 - T \cdot \Delta S^0 = -228.17 \text{ kJ/mol} \qquad (13)$$

being: ΔH^0 y ΔS^0, the thermodynamic properties with standard values. Thus, the following value is obtained:

$$E = \frac{-\Delta G}{nF} = 1.18 \ V \qquad (14)$$

This value corresponds to the fuel cell operation with pure oxygen. With air, the resulting voltage, E, will be lower, decreasing around 2%. As each fuel cell generates around 1.18 V, it will be necessary to connect the individual fuel cells in series (stacks), in order to have the industrial voltages of 12 or 24 V of dc.

Another important parameter is efficiency. The ideal efficiency (thermodynamic efficiency, η_t) takes the following value:

$$\eta_t = \frac{-n\,FE^0}{\Delta H} = 83 \ \% \qquad (15)$$

This thermodynamic efficiency is achieved, whether as a result of the reaction between hydrogen and oxygen, you get water in liquid form as the final product. If the product of the reaction (water) is in the form of steam, based on the thermodynamic properties for the H_2O (gas) is obtained:

$$\Delta H = -241.82 \text{ kJ/mol} \qquad (16)$$

$$\Delta S = -44.53 \ \text{J}/\text{mol} \cdot \text{K} \qquad (17)$$

$$\Delta G = -228.55 \text{ kJ/mol} \qquad (18)$$

Under these conditions we can say that the thermodynamic efficiency takes the value:

$$\eta_t = 94{,}5\% \qquad (19)$$

V. Polarization characteristics

In an ideal world, the theoretical optimum fuel cell voltage of 1.2 V would be realized at all operating currents. In reality fuel cells achieve their highest output voltage at open circuit (no load) conditions and the voltage drops off with increasing current draw.

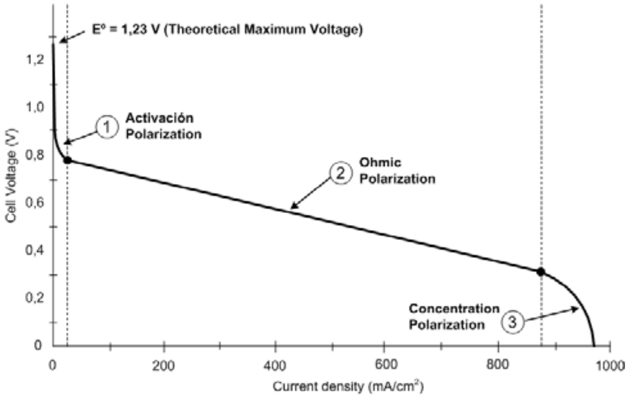


Fig.1. Fuel Cell Polarization Curve

The polarization curve characterizes the cell voltage as a function of current. The current, in turn, depends on the size of the electrical load placed across the fuel cell. In essence the polarization curve shows the electrochemical efficiency of the fuel cell at any operating current since the efficiency is the ratio of the actual cell voltage divided by the theoretical maximum of 1.2 V.

Batteries have polarization curves very much like fuel cells. Both batteries and fuel cells exhibit excellent partial load performance since the voltage increases as the load decreases. In contrast, internal combustion engines operate most efficiently at full load and exhibit a rapid decrease in efficiency at part load. Polarization is caused by chemical and physical factors associated with various elements of the fuel cell. These factors limit the reaction processes when current is flowing. There are three basic regions affecting the overall polarization:

- Activation polarization
- Ohmic polarization

- Concentration polarization

The deviation of cell potential from ideal behaviour is a direct result of the sum of these factors over the entire load range.

A. *Activation polarization*

Activation polarization is related to the energy barrier that must be overcome to initiate a chemical reaction between reactants. At low current draw, the electron transfer rate is slow and a portion of the electrode voltage is lost in order to compensate for the lack of electro-catalytic activity.

B. *Ohmic polarization*

Ohmic polarization (or "resistance polarization") occurs due to resistive losses in the cell. These resistive losses occur within the electrolyte (ionic), in the electrodes (electronic and ionic), and in the terminal connections in the cell (electronic). Since the stack plates and electrolyte obey Ohm's law, the amount of voltage lost in order to force conduction varies linearly throughout this region.

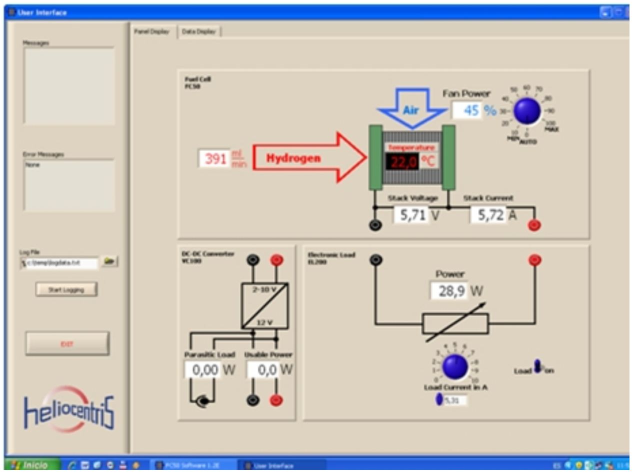
C. *Concentration polarization*

Concentration polarization results when the electrode reactions are hindered by mass transfer effects. In this region, the reactants become consumed at greater rates than they can be supplied while the product accumulates at a greater rate than it can be removed. Ultimately these effects inhibit further reaction altogether and the cell voltage drops to zero.

VI. DEVELOPMENT OF THE MULTIMEDIA COURSE

This tool multimedia enables capture the parameters of the fuel cell and graph them [3]. Subsequently, sets out a series of questions and calculations on fuel cells.

Fig.2. Main screen of the application



None
Fan Power 45 %
391 ml/min
Temperature 22,0 °C
Stack Voltage 5,71 V
Stack Current 5,72 A
Parasitic Load 0,00 W
Usable Power 0,0 W
Power 28,9 W
Load Current in A 5,31

Fig.3. Digital front panel

This information is divided into different themes, as follows:

- References and security warnings
- Characteristic curve of a fuel cell
- Parameters that influence the characteristic curve
- Determining the curve flow of hydrogen
- Efficiency of the fuel cell stack
- Efficiency of a fuel cell used as independent power supply

A. *References and security warnings*

The Hy-Expert Instructor™ fuel cell system is a laboratory instrument designed to be operated by trained personnel in education and research, it is not a consumer-oriented product, so its use is restricted. The misuse or abuse can lead to damage to the health of the operator or the system itself or other apparatus.

The fuel cell system has the following elements:

- Fuel cells, PEM type, of 50 W
- EL-200 electronic load
- Converter DC / DC
- Module LED lights
- Supply of hydrogen

The fuel cell system produces electricity low voltage converting hydrogen electrochemistry. The hydrogen is stored in pressurized cylinders, tanks hydride, or generated special hydrogen generators [4]. It must take into account the conditions of operation and maintenance that are reflected in the components.

The Hy-Expert fuel cell system is managed for installation and operation in laboratory conditioning. In particular, the room should be equipped with effective system of air evacuation to prevent the formation of explosive mixtures of hydrogen and air, as well as gas leaks. Steps must be taken against electrostatic discharge.

The local safety regulations must be observed in the facility. Applies in particular to the hydrogen storage cylinders that are not part of this system.

The catalysts and membranes of the stack are sensitive to dust and chemical reagents, Ex. H_2S and other sulphuric compounds, carbon monoxide, ammonia, chlorine compounds, solvents, etc. Therefore the system should not be in an area with the presence of these compounds [5]. Not that there irrigation casual exposure.

The fuel cell system should be placed on a stable foundation, horizontal and solid. This must be well firm. The temperature must be allowed to work between 5 and 35 ºC.

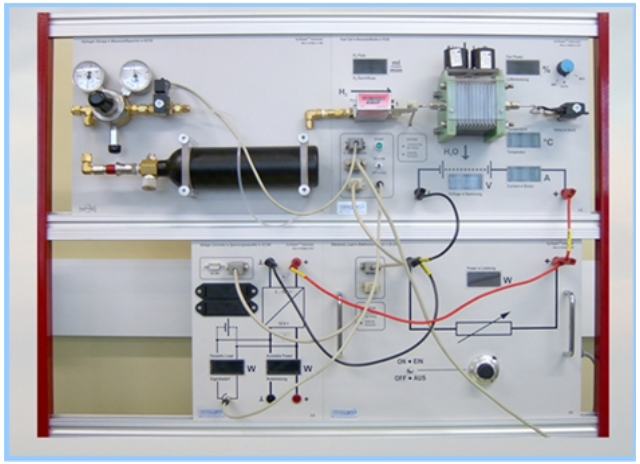


Fig.4. FC50 module with all components

TABLE II
FUEL CELL STACK TECHNICAL DATA

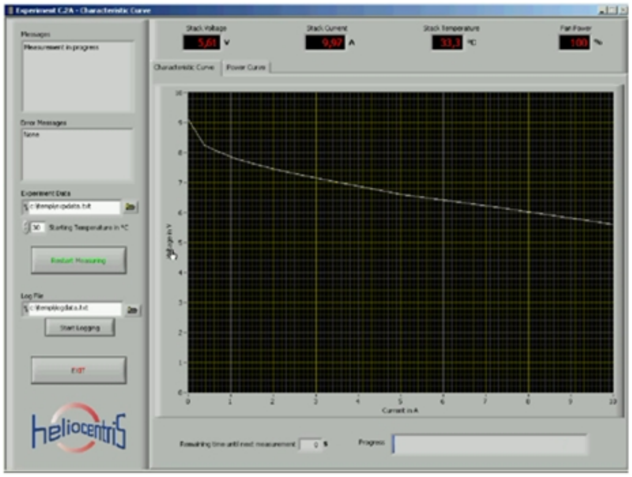
Rated power output	40 W
Maximum power output	Approx. 50 W
Open circuit voltage	Approx. 9 V
Current at rated power	8 A
Voltage at rated power	5 V
Maximum current	10 A
Hydrogen consumption during rated output	Approx. 580 NmL/min
Hydrogen nominal pressure	0.6 ± 0.1 bar gauge
Max. permissible hydrogen pressure	0.4 … 0.8 bar gauge
Max. permissible cell temperature	Operation: 50 °C Starting: 45 °C
Supply voltage	12 V DC
Power consumption	No-load operation: 5.2 W At 10 A load current: 6.4 W
Ambient operating temperature	+5 … +35 °C

B. *Characteristic curve of a fuel cell*

This section defines the curves-voltage-current and power-current of a fuel cell and are graphically represented. That will get basic knowledge of the behaviour of a FC. These results can be used for measuring and designing new fuel cells.

TABLE III
TAKING DATA

Rated Current	**Measurements**		**Calculations**
Istack (A)	**Istack (A)**	**Vstack (V)**	**Pstack (W)**
0.0	0.00	8.99	0.00
0.2	0.20	8.30	1.66
0.5	0.52	7.92	4.12
1.0	1.00	7.62	7.62
1.5	1.52	7.39	11.23
2.0	2.00	7.17	14.34
3.0	3.01	6.78	20.41
5.0	5.01	6.12	30.66
7.0	7.00	5.71	39.97
10.0	10.0	5.12	51.20



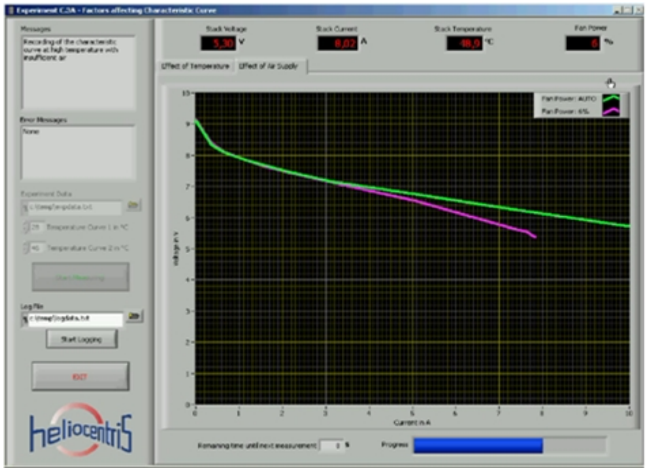
Messages: Measurement in progress

Error Messages: None

Fig.5. Characteristic curve

C. *Effect of air supply*

Figure 6 shows the performance of the fuel cell for an air suitable concentration and with reduction of air.



Messages: Recording of the characteristic curve at high temperature with insufficient air

Error Messages: None

Fig.6. Effect of air supply

In this figure can be observed three different areas to be discussed below:

Area 1: Currents from 0 to 2 Amps

This curve presents an exponential performance, because of the catalytic effects in the electrodes. In this range, the curves are almost equal for both modalities, with automatic control of the fan and the reduced supply of air (6%). The main function of the fuel cell consists on obtaining electrical and thermal power from the exothermic reaction of hydrogen and oxygen. If one of these reagents is insufficient, the reaction is partial or totally annulled.

Area 2: Currents from 2 to 7 Amps

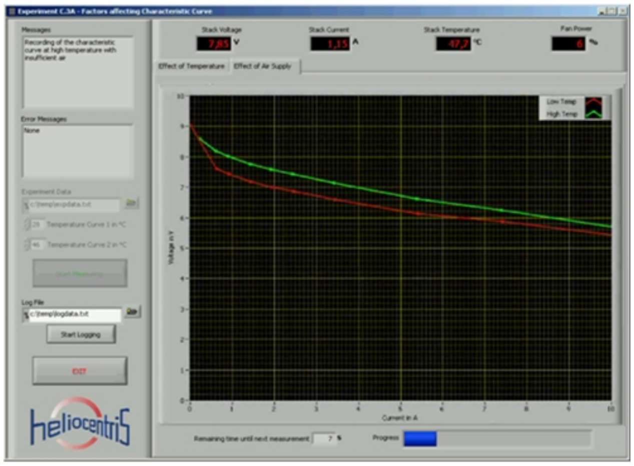
This second area presents a lineal performance. With reduced supply of air, the oxygen concentration in cathode falls depending on the load. If load current is constant, a decrease takes place in the fuel cell voltage, depending on the electrical resistance of the fuel cell. In this area, when the given air decreases, an increase of temperature takes place and the membrane dries off. This causes a lower ionic conductivity and a voltage drop.

Area 3: Currents higher than 7 Amps

Due to the high load current it is necessary a bigger quantity of oxygen through the diffusion layer of gas. The low oxygen concentration, caused by a limited quantity of air in cathode, produces a reduced diffusion in this area. When the voltage drops below 5V, an automatic device disconnects the fuel cell.

D. Effect of stack temperature

In figure 7, the characteristics of the fuel cell for two different temperatures are represented. The catalytic process can be accelerated increasing the temperature, but then the global reaction will be also accelerated. In the fuel cell, this effect appears as a bigger number of free electrons, which produce a higher current and a bigger voltage for the same current.


Experiment C.3A - Factors affecting Characteristic Curve

Messages: Recording of the characteristic curve at high temperature with insufficient air

Error Messages: None

Stack Voltage: 7,85 V

Stack Current: 1,15 A

Stack Temperature: 47,2 °C

Fan Power: 6 %

Experiment Data: c:\temp\expdata.txt

28 Temperature Curve 1 in °C

46 Temperature Curve 2 in °C

Log File: c:\temp\logdata.txt

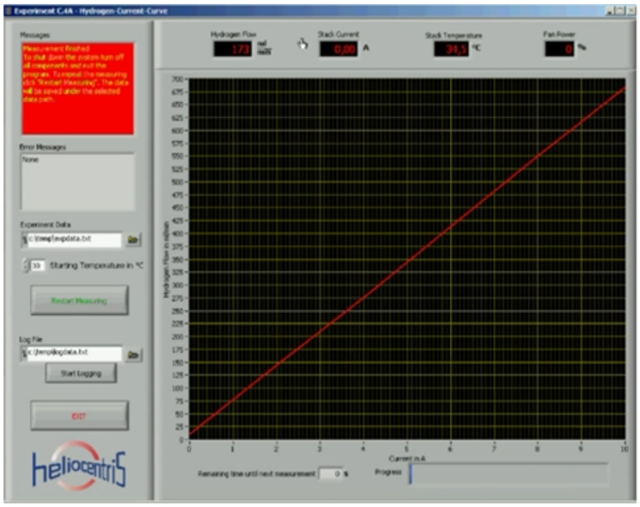
Remaining time until next measurement: 7 s

Fig.7. Effect of stack temperature

The two curves convergence for high loads can be explained by the ionic conduction of the membrane and the conduction of the electrodes in the bipolar badges. When temperature increases water evaporates easier and the membrane dries off. As protons only can go through wet membranes, the ionic conductivity decrease and electrical resistance increases. Thus, with too low temperatures the catalytic process is forced and with too high temperatures the electrical resistance increases (because a drying of membranes). To increase the operation temperature, a solution can be to humidify the air that provides oxygen. This solution is particularly attractive in stacks of high energy.

E. Effect of hydrogen flow

In this experiment we will investigate the effects of reduced air in the fan, increasing internal resistance and temperature in the characteristic curve of the fuel cell. In figure 8, how the rate of hydrogen flow is directly proportional to the current can be appreciated. This performance agrees with the first law of Faraday.


Experiment C.4A - Hydrogen-Current-Curve

Messages: Measurement finished To shut down the system turn off all components and exit the program. To repeat the measuring click "Restart Measuring". The data will be saved under the selected data path.

Error Messages: None

Hydrogen Flow: 173 ml/min

Stack Current: 0,00 A

Stack Temperature: 34,5 °C

Fan Power: 0 %

Experiment Data: c:\temp\expdata.txt

30 Starting Temperature in °C

Log File: c:\temp\logdata.txt

Remaining time until next measurement: 0 s

Fig.8. Hydrogen current curve

F. Efficiency of the fuel cell stack

This section is intended to determine the efficiency of fuel cell stack. Also, we analyze the characteristic of the efficiency of power, to gain important insights to classify fuel cells. And finally, additional two methods will be used to measure efficiency:

- Stacking efficiency in terms of tension and given the current efficiency.
- Calculate the efficiency of using the free enthalpy of the reaction, the lowest heat value (LHV) or the highest heat value (HHV).

G. *Efficiency of a fuel cell used as independent power supply*

This is to determine the efficiency of a fuel cell system independent of the network. The efficiencies of the system and the stack and measures are explained on an experimental basis. In addition examines the effect of the parasite load of the system.

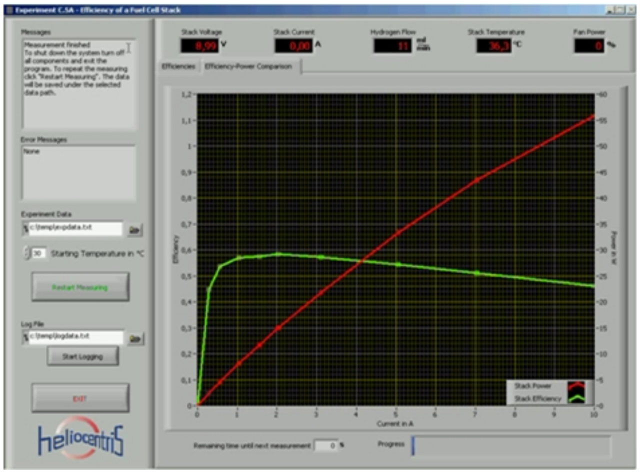
TABLE IV
TAKING DATA

Rated Current	**Measurements**		
Istack (A)	**Istack (A)**	**Vstack (V)**	**V_{H2} (ml/min)**
0.0	0.00	9.05	14
0.2	0.20	8.31	25
0.5	0.52	7.94	45
1.0	1.00	7.51	79
1.5	1.51	7.21	110
2.0	1.99	6.96	145
3.0	3.01	6.51	215
5.0	5.01	6.02	350
7.0	7.00	5.63	490
10.0	10.0	5.12	698

TABLE V
CALCULATIONS OF POWER AND EFFICIENCY

Rated Current	**Calculations**	
Istack (A)	**P stack (W)**	**η stack (%)**
0.0	0.00	0.00
0.2	1.66	0.37
0.5	4.13	0.51
1.0	7.51	0.53
1.5	10.89	0.55
2.0	13.85	0.53
3.0	19.60	0.51
5.0	30.16	0.48
7.0	39.41	0.45
10.0	51.20	0.41

In figure 9, the optimum efficiency of the fuel cell is represented. It can be seen that it appears in a range of low load. However, the optimum point of given power appears in the range of maximum current. Thus, in the design of fuel cells it is necessary to choose between maximum efficiency or maximum power.



Experiment C.5A - Efficiency of a Fuel Cell Stack

Messages: Measurement finished To shut down the system turn off all components and exit the program. To repeat the measuring click "Restart Measuring". The data will be saved under the selected data path.

Error Messages: None

Experiment Data: c:\temp\expdata.txt

30 Starting Temperature in °C

Log File: c:\temp\logdata.txt

Stack Voltage 8,99 V

Stack Current 0,00 A

Hydrogen Flow 11 ml/min

Stack Temperature 36,3 °C

Fan Power 0 %

Remaining time until next measurement 0 s

Fig.9. Power and efficiency of stack

Considering the aspect of good efficiency, the injected fuel becomes electrical and thermal power efficiently. However, the fuel cell presents a higher maximum power nevertheless of which should be used and, in consequence, bigger weight, volume and cost. This efficiency is particularly interesting in static applications, for which weight and size are not outstanding qualities and fuel cells operate long periods of times with constant load. Thus, their use in electrical power plants is advised.

On the other hand, if the fuel cell works to the optimum power, a reduction of weight, volume and cost can be contemplated, in spite of a worse use of fuel. This operation modality is revealed as particularly attractive for mobile applications, since the fuel cell should be transportable, for example, in the automobile industry.

VII. IMPLEMENTATION OF THE FUEL CELL. CASE1: LED SEMAPHORE

When using a fuel cell system as a separate provision power consumption, is necessary to anticipate that it will take for a given period. Knowing the amount of fuel, can be calculated how much fuel is needed to store. Using the example of a traffic light, this experiment aims to determine the amount of fuel required for a certain period and the volume of storage required. In addition, compared different methods of storing hydrogen, and compares with operating with battery.

The knowledge gained will be applied to conduct to the implementation of the fuel cell to traffic lights with LED technology, uninterruptible power supplies (UPS), to solve the problem of interruptions in electricity supply and the dangers and risks involved in the movement in these conditions.

The objectives to consider are the following:

- Present the benefits of traffic lights with LED technology, low consumption, high brightness (even in appalling conditions) and its long duration, compared with the conventional incandescent lamps.

- Implement fuel cells to lights, where there are temporary cuts in electricity supply in order to minimize potential road accidents. In these situations, through a UPS hydrogen would have a temporary electricity supply, ensuring continuity of service.
- Quantify the volume of stored hydrogen to power the battery for a specified period of time.
- Analyze the decline of emission of polluting gases by using technology more efficiently.

To start calculating the power of a traffic light with LED technology industrial applications, from the module of traffic lights bank Hy-Expert Instructor. In how many we have LED lights of each module TL10, and at traffic lights industrial dimensions ranging from 200-300 mm. Also, the number of LEDs typically vary depending on the provider. Our calculations are based on data collected from the test Hy-Expert Instructor, where after obtaining the necessary data on the power and hydrogen consumed, have been extrapolated to a real traffic light. In our case the lights selected to make the calculations has been 300 mm.

A. Power consumption

Data obtained on the display of test:

P_{red} = 2.2 W = 12 I => I = 2.2/12 = 0.183 A
P_{green} = 1.6 W = 12 I` => I` = 1.6/12 = 0.133 A
P_{amber} = 2.3 W = 12 I``=> I``= 2.3/12 = 0.191 A

Taking into account the number of LEDs are in a traffic light, we get the following consumption:

P_{red} = 2.2 W 50 LEDs
P_{green} = 1.6 W 50 LEDs
P_{amber} = 2.3 W 50 LEDs

Then calculate the power consumed by an LED, red, green and amber, and extrapolate what a real LED lights.

Power of one LED

Power of an LED = Psemaphore of test / Number of LED lights test:

$P_{LED\ red}$ = (2.2 W / 50 LEDs) = 0.044 W
$P_{LED\ green}$ = (1.6 W / 50 LEDs) = 0.032 W
$P_{LED\ amber}$ = (2.3 W / 50 LEDs) = 0.046 W

Power of one traffic light

P_{sph} = 0.044 · 208 LEDs = 9.152 W red
P_{sph} = 0.032 · 208 LEDs = 6.656 W green
P_{sph} = 0.046 · 208 LEDs = 9,568 W el amber
P_{sph} = 0.044 · 60 LEDs = 2.64W pedestrian arrow-red
P_{sph} = 0.032 · 60 LEDs = 1.92 W pedestrian arrow-green

B. Hydrogen flow consumed

Red LED H_2 consumption: 20/50 = 0.4 ml/min
Green LED H_2 consumption: 15/50 = 0.3 ml/min
Amber LED H_2 consumption: 24/50 = 0.48 ml/min
Thus, the consumed hydrogen by semaphore:

Red semaphore H_2 consumption:

0.4 · 208 = 83.2 ml/min

Green semaphore H_2 consumption:

0.3 · 208 = 62.4 ml/min

Amber semaphore H_2 consumption:

0.48 · 208 = 99.8 ml/min

Pedestrian arrow-red H_2 consumption:

0.4 · 60 = 24 ml/min

Pedestrian arrow-green H_2 consumption:

0.3 · 60 =18 ml/min

C. Calculation for an intersection with three traffic lights (three in the worst case)

The worst case is that which consumes more power or hydrogen. This course will not be on a permanent basis, but will vary and there will be moments in which the consumption of electric power and hydrogen will be lower. As far as we are oversize calculations.

(amber semaphore + red semaphore + pedestrian arrow-red)

99.8 + 83.2 + 24 = 207 ml/min
9.568 + 9.152 + 2.64 = 21.36 W

To calculate both the consumption power of hydrogen as a crossroads of three traffic lights will do the following: multiply the data obtained in the worst case of three, who are crossing lights that look.

D. Power consumption

The power required to provide traffic lights is:

$$21.36 \cdot 3 = 64.08 \text{ W}$$

But these lights to be powered by an alternating current will have to use an investor. The performance of this investor is 90%, so it must be multiplied by 1.1 the value we have gained and get the actual consumption. Thus,

64.08 · 1.1 = 70.488 W consume three traffic lights

E. Consumption of hydrogen

The total consumption of hydrogen is:

$$207 \cdot 3 = 621 \text{ ml/min}$$

In this result we must add 25 ml/min, as you will need to supply the fan, display, etc., that will have to take the actual traffic lights.

621 + 25 = 646 ml/min are needed to supply the lights

F. *Duration of a bottle of hydrogen*

The calculations are made for a bottle of 50 litres to 200 bars. We must also take into account that the bank's fuel cell test absorbs hydrogen at a pressure of 0.6 bars.

This bottle has a compression factor of 1.132, so it contains 8834 Nm^3. Thus, 8834 litres at the pressure of 1 bar, relate 14723 litres to the pressure of 0.6 bar.

Therefore, the duration of the bottle of hydrogen to feed the industrial installation of three traffic lights, at all times be as follows:

Time = Volume / Flow = 14723 l / 0.64612 l / min = 22787 min = 15 days and 19 hours

This result is in the worst case, bringing into reality the duration will be longer.

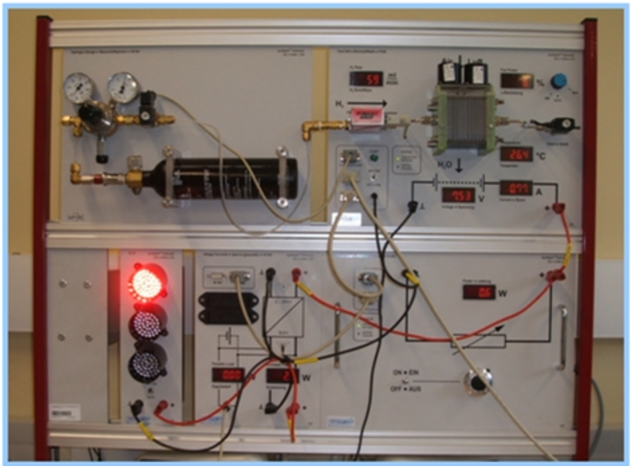


Fig.10. Module FC-50 feeding LED semaphore

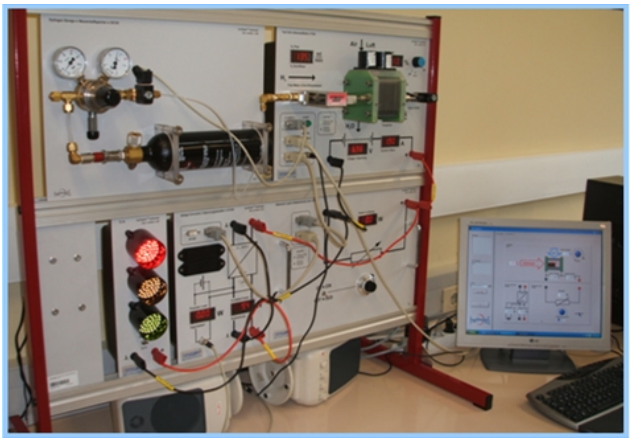


Fig.11. Computer Management of LED semaphore

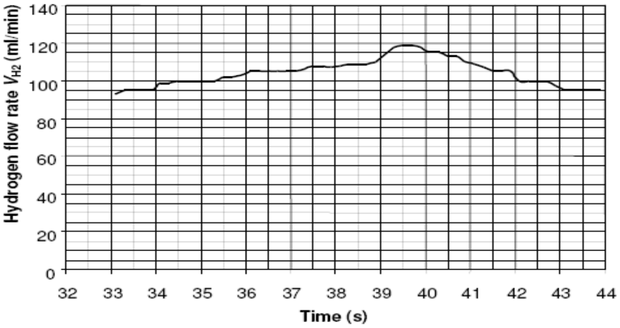


Fig.12. Hydrogen flow rate in a traffic-light cycle

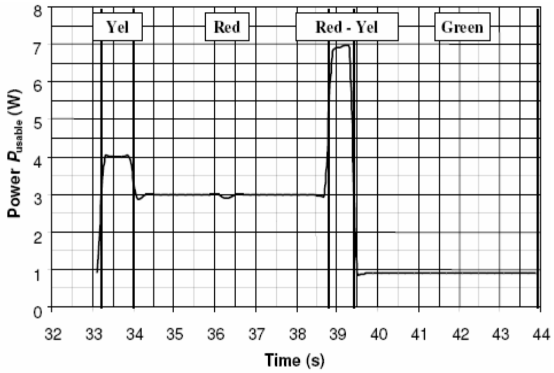


Fig.13. Power demand in a traffic-light cycle

VIII. IMPLEMENTATION OF THE FUEL CELL. CASE2: LIGHTING

Once launched the fuel cell module, you connect as electrically charged three high-efficiency lamps, 11 W each, which provide a flow equivalent to a bright lamp of 100 W, 220 V and 50 Hz frequency.

As the electrical charge runs to 220 V and 50 Hz frequency, will require an investor to convert the 12 V DC at the outlet of the regulator, in 220 V and 50 Hz frequency. The figure 14 shows the arrangement complete the module.

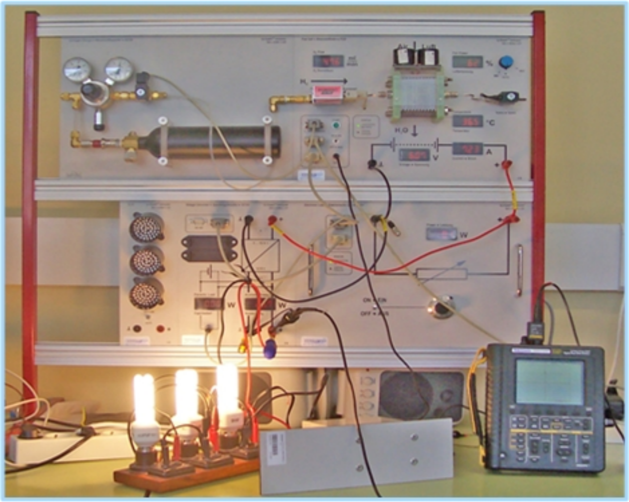


Fig.14. FC module with high efficiency lamps

A. Technical data acquired experimentally

The data obtained are as follows:

- Average H_2 consumption: 25.56 l/h
- Regulator output power average: 32.2 W
- Regulator output voltage: 12 V dc
- Inverter output power average: 27.1 W
- Output voltage investor: 230 V ac
- Current in the load: 124 mA ac
- Power factor in load: 0.95 inductive
- Inverter efficiency: 27.1 / 32.2 = 84%

These data were taken by a digital meter and the module itself FC50.

Then analyze the cost of kWh produced, with hydrogen fuel cell purchased and produced by hydrolysis.

B. Cost per kWh produced in the FC50 with purchased hydrogen

Our source of hydrogen stored 50 l to 200 bars (16666 l to 0.6 bars). This is the admission pressure of our fuel cell. The bottle of 50 litres to 200 bars, has a compression factor of 1.132, thus has a volume of:

$$0.050 \cdot 200 / 1.132 = 8.834 \text{ Nm}^3$$

The cost of bottled hydrogen is 92.5 €, so the hydrogen to 0.6 bars would cost:

$$0.0055 \text{ €/l}$$

Because we need to calculate the price of 1 hour and hydrogen consumption is 25.56 l, the cost would amount to 0.141858 €.

With this cost would be able to generate 27.1 Wh, hence, to produce 1 kWh, will be required:

$$5.23 \text{ €/kWh}$$

C. Cost per kWh generated in the FC50 with hydrogen produced by electrolysis

The generation of hydrogen through electrolysis is approximately 4.5 kWh / Nm^3 H_2.

One cubic meter, the pressure of 0.6 bars, took 1.688,3 litres. If we generate hydrogen electrolysers with a fed a power grid, the cost of kWh, in the rate 2.0 of LT, is 0.086726 €/kWh. The cost of compressing 1 Nm^3 H_2 is 0.9 kWh, hence, the generation and compression to 200 bars of 1688.3 litres will be:

$$(4.5 + 0.9) \text{ kWh} \cdot 0.086726 \text{ €} / \text{kWh} = 0.4683204 \text{ €}$$

Thus, the cost of 1 litre will be: 0.00027739 €

Comparing the litre of hydrogen, purchased and generated, it appears that the former is 20 times more expensive. Thus, to produce 1 kWh will be required:

$$0.2615 \text{ €/kWh}$$

IX. CONCLUSION

This paper has presented a study of the technology of the PEM fuel cell within the field of renewable energy [6], trying aspects ranging from storage of surplus renewable energy in the form of hydrogen, until the applications of this kind of fuel cells. In our case, we have developed an application of the fuel cell to traffic lights with LED technology, uninterruptible power supplies (UPS).

Emphasize the importance of the implementation of fuel cells to semaphores, to avoid temporary cuts in electricity supply in order to minimize potential road accidents. In these situations, through a UPS hydrogen would have a temporary electricity supply, ensuring continuity of service.

Finally it should be stressed that with this application carried out, if used in hydrogen fuel cell was generated with renewable energies [7], each kWh of electricity generated in comparison with that from coal-fired power stations, avoid:

- 0,60 kg CO_2, carbon dioxide
- 1,33 gr SO_2, sulfur dioxide
- 1,67 gr NO_x, nitrogen oxides

with the resulting benefit to the environment.

With respect to the cost analysis kWh can highlight the following actions to mitigate its price:

- Increase the efficiency of the fuel cell, whose maximum yield is 0.58 and the nominal 0.48 (remember that is a stack of application teacher).
- The return on investment is low (84%), when industrialists exceed 90%. The used in our case is 70 W nominal and power is applied less than 40 W, then you are not working with the wattage. It is recommended, therefore, use a inverter more adjusted to the rated output.
- The power of electrolysers should take place through surplus renewable energy, cheaper and cleaner.
- If the foregoing is not possible, could generate hydrogen during the night to night, approximately 55% cheaper than the daytime.

In short, an increase in efficiency in the generation of hydrogen devices and in the transformation of it into electrical energy, all with the least pollution and in an environmentally-friendly [8].

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