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"HYDROGEN AS FUEL. FROM ELECTROLYSIS TO FUEL CELLS"

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ABSTRACT

STEM approach is a well-known pedagogical and teaching method, especially for Natural Sciences teachers. This is because Scientific is based on the major steps of STEM approach. Primarily, a scientific question is being applied, or a science theory had to be tested. Then we were asked to test the theory or attempt to provide some answers to our scientific questions. We have then to perform an experiment using technology and engineering. Finally, in order to process our findings, we must use mathematical approaches. We followed these major steps to compose an educational scenario about water electrolysis and how Hydrogen as an electrolysis product can be used as fuel. We mainly focused on experimentation (electrolysis apparatus) and manufacturing of a compact fuel cell that consumes hydrogen and product's energy. We integrated this STEM approach under a historical frame regarding water as a power source since hundred years ago.

KEYWORDS: *STEM, Water, Hydrogen, Fuel Cell, Electrolysis, Water Distillation, Renewable Energy Sources*

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INTRODUCTION

In recent years, gradually, all educators are realizing that traditional educational methods are not any more attractive. Students are not any more willing to attend lectures and incubate knowledge according to an inelastic curriculum [1]. Especially, younger students in Primary Schools and even in Junior High Schools are regarding this way of teaching as old fashioned and many times as extremely boring [2]. In order to face this situation, teachers and educators proposed some alternatives in teaching. Since 1970's the Nuffield project attempted to develop students' skills, introducing inquiry-based learning methods [3]. On the other hand, STS (Science-Technology-Society) projects aimed to integrate Society and Technology to Science [4]. Although, they total innovative education approaches these attempts failed mainly because teachers and educators were not ready to apply such teaching methods, or because students were unable to act as young researchers due to many different reasons [5].

At the end of 80's under the pressure of the National Commission on Excellence in Education, USA proposed the "Project 2061", a long scale (until the year 2061) project that aimed to total reform education towards a more realistic, implemented and inquiry-based direction strongly connected to society [6]. Many other countries (Canada, England, New Zealand, Australia) followed this global trend in education under the philosophy "Science for All". Even more, just after year 2000 many countries all around the world and mainly EU members realized the need of bonding Science and Society, thus their proposed wide educational projects based on the STEM philosophy under the axis of

inquiry-based learning steps. “Beyond 2020” and 21st Science Century were some of the most pronounced projects, including STEM activities [7]. In Greek educational system STEM projects are mainly introduced through educational programs(not obligatory), project courses (obligatory) and Creativity Groups (only for Experimental Schools). Although, recently all teachers are encouraged to apply to such activities in their everyday teaching practice introducing integrated project within the course session.

STEM in Natural Sciences Teaching

Natural Sciences are strongly related to STEM philosophy mainly because of their experimentation. All different Natural Sciences subjects are based on experiments and observation followed by data process. STEM includes Science, Technology, Engineering and Mathematics. Science is at the core of Natural Sciences, while we need scientific rules, theories and laws to develop our scientific questions and from our answers respectively [8]. Continuously, Technology and engineering are necessary to develop our experiment and record experimental data [9]. Engineering while we have to construct an apparatus and technology because if we wish to record data, this can be done with accurate and reliable way through recording sensors. Of course, we must mention that our sensors must be well defined and precisely calibrated, but this is a part of engineering. Finally, mathematics will critically contribute to data process, while all-Natural Sciences law was depicted after plotting recorded data and adjusting a fitting curve to this data plot.

On the other hand, inquiry-based learning is also very well fitted to Natural Sciences teaching. Inquiry-based method is based on primarily setting a scientific question, then looking for primitive answers based on former knowledge [10]. Following an inquiry-based learning method is encouraging students to perform an experiment in order to collect themselves the evidences to support or revise their primitive knowledge. Finally, all participants are asked to present their findings after the procession and support their scientific conclusions. It’s obvious that STEM and inquiry-based learning method are in greater accordance, so they can be combined in an ideal way [11]. Actually, both approaches are mirroring a well known scientific technique of revealing natural sciences, laws, firstly introduced by Galileo. Thus, if we wish to transform students into tinny researchers, we have prior to teach them through STEM philosophy and under an inquiry-based learning method.

Renewable Resources – Hydrogen as a Fuel

Our teaching proposal entangles both renewable resources and Hydrogen fuel cells under a STEM approach. First of all, we introduce students to water power used hundred years ago as an energy resource for pre-industrial development. We refer to water mills and how they provided the necessary energy for agricultural purposes as production of oil, flour and other products. We also refer to the use of water mills in production of gunpowder influencing thus the global history. Continuously we gradually connecting the pre-industrial times to modern times, focusing on the very promising fuel cells based of course on Hydrogen as a fuel. This part is mainly the scientific part, while the technological and engineering part includes the experimentation where we use an electrolysis apparatus to present to students how can we cause decomposition of water into Oxygen and Hydrogen.

This procedure is easy to be achieved and need just a battery of almost 9V of voltage. Students are asked to find out how electrolysis will start e.g. the appropriate voltage and the water-acid solution needed to perform electrolysis, as we need an electro conductive solution. Students also are recording the portion of gases collected during electrolysis. Then we trigger students to find other ways of providing energy for electrolysis. One of the most effective and renewable

resources is solar energy. We perform electrolysis by using solar energy and then the collected hydrogen is used to provide the necessary energy for rotating a motor. Clearly, we use solar energy to produce a fuel for future use. Technologically we tested and evolved a fuel cell for both activities, electrolysis of water to hydrogen and then use hydrogen as a fuel for energy production purposes. Finally, through mathematics, we made all kinds of procession of our recorded experimental data.

STEM STEPS OF THE EDUCATIONAL SCENARIO

First of all, we must mention that this educational scenario was applied in real teaching conditions during the course "project" entitled "From Water power to Fuel Cells". You can find relative information to the following link: https://m.facebook.com/ApoToYdorStoYdrogono/ (retrieved 6/4/2018). Apart from this project an upgraded version of this project was applied in the international contest Odysseus II in the year 2017, winning in the Regional Finalists in the Pioneers and Explorers category for Greece / Bulgaria / Cyprus the Prize of "the most socially relevant project". Thus, our project has a strong connection to space technology and innovation.

Science

In pure water at the negatively charged cathode, a reduction reaction takes place, with electrons (e^-) from the cathode being given to hydrogen cations to form hydrogen gas. The half reaction, balanced with acid, is:

Reduction at cathode: $2\ H^+(aq) + 2e^- \rightarrow H_2(g)$

At the positively charged anode, an oxidation reaction occurs, generating oxygen gas and giving electrons to the anode to complete the circuit:

Oxidation at anode: $2\ H_2O(l) \rightarrow O_2(g) + 4\ H^+(aq) + 4e^-$

The same half reactions can also be balanced with base.

Overall reaction: $2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$

The number of hydrogen molecules produced is thus twice the number of oxygen molecules. Assuming an equal temperature and pressure for both gases, the produced hydrogen gas has therefore twice the volume of the produced oxygen gas. The number of electrons pushed through the water is twice the number of generating hydrogen molecules and four times the number of generating oxygen molecules. We must mention that we performed our experiment by using acid H2SO4. Finally, experiments from the collaborative laboratory shows that this innovative fuel cell can adsorb water in vapor state from ambient air and perform decomposition, which is indeed very promising.

Engineering

The main idea (scientific question) of our project is how to produce energy during a long space trip, for instance to Mars or further. First of all, we considered that from water electrolysis we can produce Hydrogen which is actually a very effective fuel. Thus, we constructed an electrolysis apparatus and performed an experiment of splitting water into Hydrogen and Oxygen (Figure 1).

Figure 1: The Electrolysis Apparatus

We used a battery for splitting water, but then the problem of energy consuming occurred. Thus, we proposed the alternative of using solar energy, by a photovoltaic solar panel to split water. We constructed the representative apparatus and recorded the water splitting to Hydrogen and Oxygen (Figure 2).

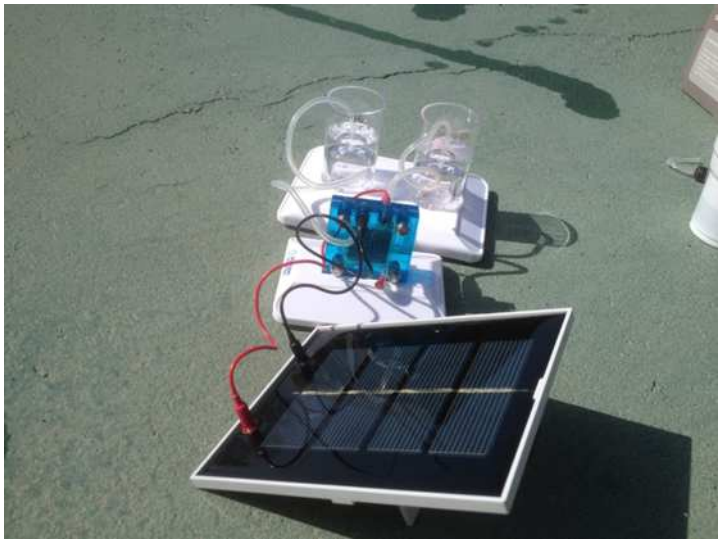

Figure 2: Water Splitting using Solar Energy

Then, the next step was to use Hydrogen to produce energy. The best way of achieving this is to use a fuel cell connected to a motor. We, indeed, constructed the relevant circuit, setting in function a motor and rotating a mounted propeller (Figure 3).

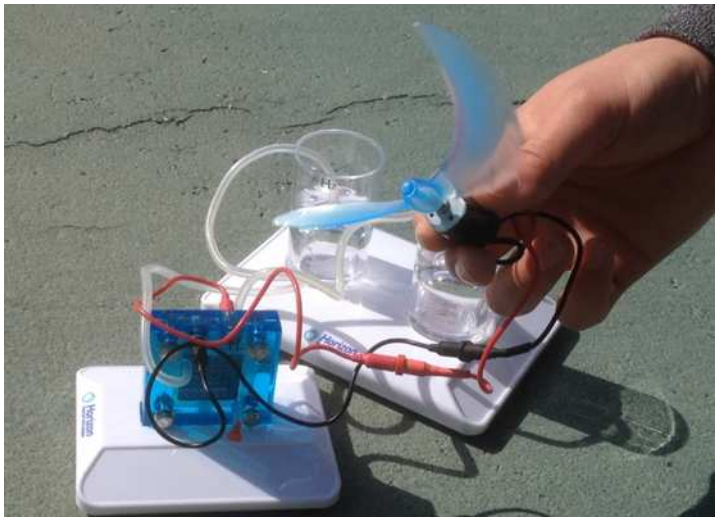

Figure 3: Using Produced Hydrogen as Fuel for Functioning a Motor

Continuously, we considered how we can recycle water, or distilled contaminated water to use it in our fuel cell. Recycling of water is of high importance during a long space journey, while the water supplies cannot be unlimited. Thus, we constructed a distillation apparatus and performed a distillation collecting pure water using it, then for hydrogen production through water splitting (Figure 4).

Figure 4: Distillation of Contaminated Water

Furthermore, observing the electrolysis experiment we wondered how electrolysis can be formed in space (zero gravity conditions), while the air bubbles cannot move towards a specific direction and collected in the upper part of a glass tube.

Technology and Mathematics

Additionally, within the framework of preserving water we considered the possibility of collecting humidity of ambient air in a spacecraft. In order to overcome these problems, we contacted Professor M. Tsampas from the Dutch

Institute for Fundamental Energy Research, we set our problematic and he proposed as a new type of fuel cell [12]. Furthermore, with his research team performed a series of measurements, providing solutions about gas (hydrogen) collected in space and use of vapor water (ambient).

In the following Figure 5 you can see the measurements performed by the FOM Institute DIFFER at the Dutch Institute for Fundamental Energy Research for use in collaboration with professor M. Tsampas.

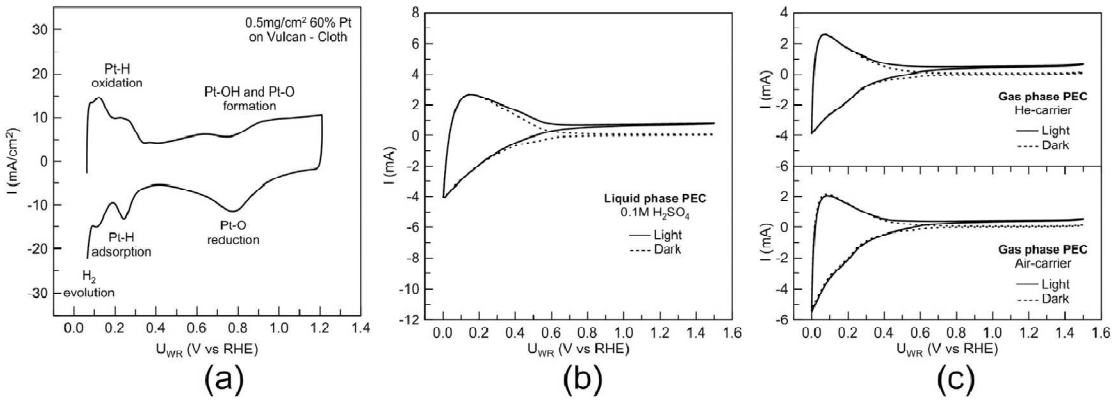

Figure 5: Cyclic Voltammetry Curves on a Hybrid Fuel Cell Produced by the FOM Institute DIFFER

What we are now thinking of, is distillation of human excretions so we can also collect water. The main problem is that the boiling point is the same with the water, so we have to separate the other substances somehow. We are now testing different types of filters without having a successful result yet.

INQUIRY BASED LEARNING MODEL

Provoke Curiosity-Former Knowledge-Experimentation

During this project we followed the steps of inquiry-based learning methodology. First of all, we set the main scientific question: “How can we produce and store energy during long space journeys?” Then we started thinking of possible answers. We referred water mills used in the past to produce agricultural products such as flour, olive oil, etc. Then the main idea was focused on hydrogen as fuel and fuel cells. We proposed to student’s water electrolysis, that we can split water into Hydrogen and Oxygen. We used the Hoffman electrolysis apparatus with two glass collecting tubes calibrated for precise measurements, providing accurate results that are quantifiable. The apparatus was operated on a 9-V battery. At the bottom of the glass tubes platinum electrodes are mounted. At the top of the glass collecting tubes, built-in thistle tube and stopcocks were adjusted for easy, no-mess filling (Figure 1). In the middle filling glass tube, we add distilled water and then we dilute 50-100 ml of H_2SO_4. Just after the connection of the 9V battery we are starting detecting bubbles gathered on the top of the two glass collecting tubes. We observe twice as much gas collected in one tube in comparison to the other tube.

New Knowledge Gained through Inquiry-Based Learning

We propose an alternative energy source and storage. Dwindling petroleum reserves and major ecological problems (greenhouse effect, climate changes, etc.), immerse renewable energy sources as highly desirable. Solar energy can cover our global energy needs, but storage of solar energy is essential. Fuel cells and especially PEC hydrogen production can potentially become a major energy provider. Towards this direction we want to orient students, teachers, parents and thus whole society and show them that green energy can be as efficient as energy produced from hydrocarbons.

All interests, but also the whole society must learn that environmentally friendly energy produced by hydrogen is apart from feasible, easy to be produced and can potentially provide energy efficiency. Also, the simplicity of the aforementioned devices further enforces the trend towards a change. Additionally, adsorption of ambient humidity has been often crucial and desirable (e.g. At houses, museums, etc.) and even impressive if simultaneously can also provide energy from water splitting and hydrogen storing. We can thus understand that fuel cells can crucially assist towards a better life quality in modern cities and societies.

CONCLUSIONS

First of all, we recorded the water decomposition (splitting) Voltage around 7-8 Volts. The respective current intensity is around 5-6 Amperes. The duration of electrolysis is almost 40 minutes. By connecting a 9V battery, electrolysis started immediately. We used platinum electrodes and we added at the distilled water sulfuric acid (H_2SO_4) 25% w/w. We had to do some tests to find the proper acid concentration. At the beginning of electrolysis, we filled the Hoffman apparatus with dilute (25% w/w) acid – water solution until the solution reaches the level of 16 ml on the gas collecting glass tube. After a short period (almost 20 minutes) of water splitting we observed at one collecting glass tube that the solution level was at 36 ml, while on the other tube it was at 26 ml. In the first tube hydrogen was collected, while on the other tube (26 ml) oxygen was collected.

We detected our primary assumption of the gases collected by turning the built-in thistle tube and stopcocks. We filled test tubes with the gases. We did this by putting a test tube full of water upside down in a trough of water and connecting a rubber tube to the syringe. Gas was propelled into the tube and tested in the usual way: for hydrogen using a lighted splint, and for oxygen using a glowing splint.

Secondly, following the same experimental philosophy, we used solar energy to perform the decomposition of water. We used a fuel cell in the electrolysis mode getting energy from a 0.75 Watt connected solar cell (photovoltaic). We determined the minimum voltage for water decomposition around 4-5 Volts, enough to cause water splitting decomposing water into Hydrogen and Oxygen. Hydrogen and Oxygen were collected into two plastic plug pins. Accordingly, the fuel cell was disconnected from the solar cell and connected to a motor with a mounted propeller. In the Fuel Cell mode electricity was generated from hydrogen and a motor propeller was motorized for a couple of minutes. Although, the main problem of gas collection in zero gravity conditions remains. Professor M. Tsampas from the Dutch Institute for Fundamental Energy Research proposed as a new innovative polymeric electrolyte membrane (PEM) photo electrochemical (PEC) fuel cell. These PEM-PEC fuel cells have some remarkable advantages: a one-dimensional ordered nanotube architecture that offers a wide specific surface and an excellent electrical channel for charge transfer that facilitates the separation of the pathogene rated electron hole pairs (Image 6). Moreover, the one dimensional (1D) and highly ordered nanotube architecture offers an excellent electrical channel for vectoral charge transfer, resulting in a significant improvement of the photo electrochemical performance. Finally, the innovative elements of the cell lie in the reactor and the photo electrode design, and this design can be further increase solar spectrum absorption.

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