A Comprehensive Construction of Hydrogen-Hydrogen-Oxygen (HHO) Cell as Renewable Energy Storage

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Abstract:- In this paper, we propose a comprehensive design of HHO generation cell of the brown gas using three different design models, namely: parallel plates design for HHO cell, cylindrical tubes design for HHO cell, and spiral plates design for HHO cell. Extensive experimental results for the plate's parameters such as resistance, inductance and capacitance are proposed to get more insight into the proposed designs. The simulation data showed that minimizing the voltage at least to be 1.23V, will increase the effective current, hence improving the efficiency. On the other hand, shaping the input signal to the energy generation system, will lead to stabilizing the temperature and reduce the power loses.

Keywords:- Clean Energy Storage, Efficiency, Electrolysis, HHO Cells, Photovoltaic, Electricity Storage.

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1 Introduction and Related Research

Generally, energy consumption is usually defined as the amount of energy or power used by individuals, industries, and countries. In the last decades, the annual world energy consumption increased rapidly for the last two decades which causes a rapid increase in environmental pollution thus push up the global warming to be a serious threat to our earth. Figure 1 shows the world's energy consumption where the global primary energy consumption grew strongly in 2017, led by natural gas and renewables, with coal's share of the

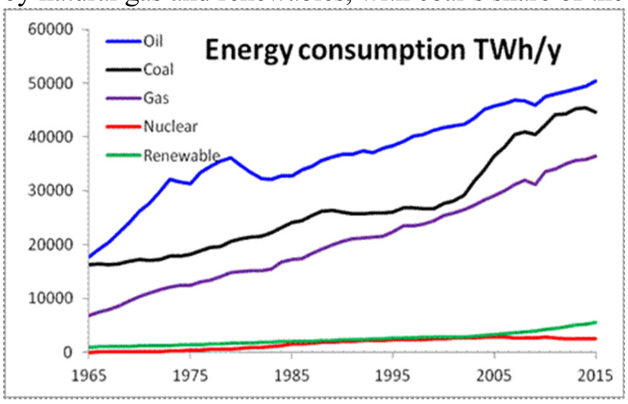

Fig.1. The world's energy consumption (2015 data) [1].

To reduce the pollution associated with power generation and storing, many efficient solutions that will reduce pollution to maintain safe environment for us and generations to come. One possible contemporary solution is the utilization of renewable energy such as the use of Hydrogen-Hydrogen Oxygen (HHO) cells which is considered as clean and relatively non-harmful source of energy [2]. Hydrogen-Hydrogen Oxygen (HHO) cells [3] are newly developed innovative solution to store energy with no harm effects for any of the beings on earth. HHO generation cells are introduced to be a green alternative energy storage source because of its advantages, which have overcome the environment pollution and global worming issues.

HHO generation cell is environmentally friendly because the hydrogen burns completely without creating pollutants, toxic fumes, or public nuisance. Therefore, significant number of researches and experimental projects are being conducted around the world to optimize the exploitation of renewable energy using HHO Cells. For instance, M. Streblau, et. al [4] studied the operation of Hydrogen-Hydrogen-Oxygen (HHO) cells by varying the electrolyte parameters, concentration and temperature and monitoring the amount of gas produced per unit time compared to the electricity input. Their experimental results showed that energy processing time is exponentially proportional with the concentration of the electrolyte and thus the determination of the efficiency of the cell at higher temperatures by MMW is limited by the inability to account the amount of water vapor contained in the generated gas mixture. While R. M. Ahmad et.al. [5] proposed an on-board dry-cell HHO generation unit powered from a local photovoltaic (PV) system with variable-step P&O MPPT technique used to extract the PV panel power with minimized power oscillations without degrading the convergence time and thus the generated Hydrogen is then utilized to enhance the fuel consumption of a diesel engine. Similar noticeable state-of-art researches were proposed in [6-11].

In this paper, we propose a comprehensive design of HHO generation cell of the brown gas using three different design models, namely: parallel plates design for HHO cell, cylindrical tubes design for HHO cell, and spiral plates design for HHO cell. Extensive experimental results for the plate's parameters such as resistance, inductance and capacitance are proposed to get more insight into the proposed designs. The rest of this paper is organized as follows: Section II provides the hardware design including the supplies and shaping circuits, power measurement circuitry, temperature measurements circuitry, control switches and valves, safety bubbler, and actual models for HHO cells. Section III describes the unit testing and system integration with extensive experimental results. Finally, section IV concludes the paper.

2 Proposed Hardware Design

Unlike traditional battery, Hydrogen-Hydrogen Oxygen (HHO) cells are newly developed innovative solution to store energy with no harm effects for any of the beings on earth. Table 1 shows a comparison between HHO cell and battery from different aspects. In terms of availability, battery in the market is more available than the HHO cell due to the common think that the battery is the only energy storage element introduced to the world.

Another aspect is the durability of the system; HHO cell is more durable because it constructed from special type of stainless steel (Type 304) that can last for more than twenty years without rust [12] while the batteries approximately last for 2-5 years depending on its fabrication material before they become decompose and need for recycling.

Regarding the environmental impact, HHO cells considered as a green energy element that no bad effect on the environment as its wastage is distilled water & can be used for drinking whereas the batteries cause pollution because of the leakage of chemical substance or gases emission emerging from batteries that may cause harm for people, animals & earth.

Table1: HHO Cell vs Battery from Different Aspects.

	HHO cell	**Battery**
Availability	Limited, in research phase	Available
Durability	Long time > 20 years	Usually 2-5 years
Component	Stainless steel	Chem-substance (Lead, sulfuric acid, ithium)
Environmental impact	No bad impact	Cause pollution, Global warming
Cost	Less expensive short/long term	Expensive for short/long term
Storage capacity	Small storage space	Large storage space
System waste	Environmentally friendly distilled water.	Environmentally harmful gas emission
Scalability	Scalable	Scalable
Efficiency	---	Below 70%
Large-scale cost	Very low	Very high

Moreover, although the construction cost of small scale HHO is more expensive than battery as it still in the research phase, large scale facilities are much less cost than large scale batteries storage facilities. Also, large scale facilities of HHO cells provides much higher lifetime and larger storage capacity with no harmful effect as well as no recycling stage is needed in the. Both technologies are scalable since the size of the storage element will vary depends on the application type. The efficiency for the battery was found to be around no more 70% [13] whereas the efficiency of HHO cell could not be determined because HHO cells are in research phase and it's an application dependent technology. It's expected to be much lower and as farther research development expected to increase.

The overall system view is provided in Figure 2 which shows the practical overview for the proposed HHO cells system along with the comprehensive integrated circuit design of HHO generation cells. Once the power is delivered to the cells, electrical current will flow in the water via the stainless steel. As a result, the water will start to be converted to HHO gas due to electrolysis. After that, the gas will flow through the piping system to the bubbler which is already filled with water to act as insulation. Out of the bubbler, the gas will flow to a container filled with water. The coming gas will be stored in this course, and it will displace the water into a level tube to calculate the gas quantity via the displaced water.

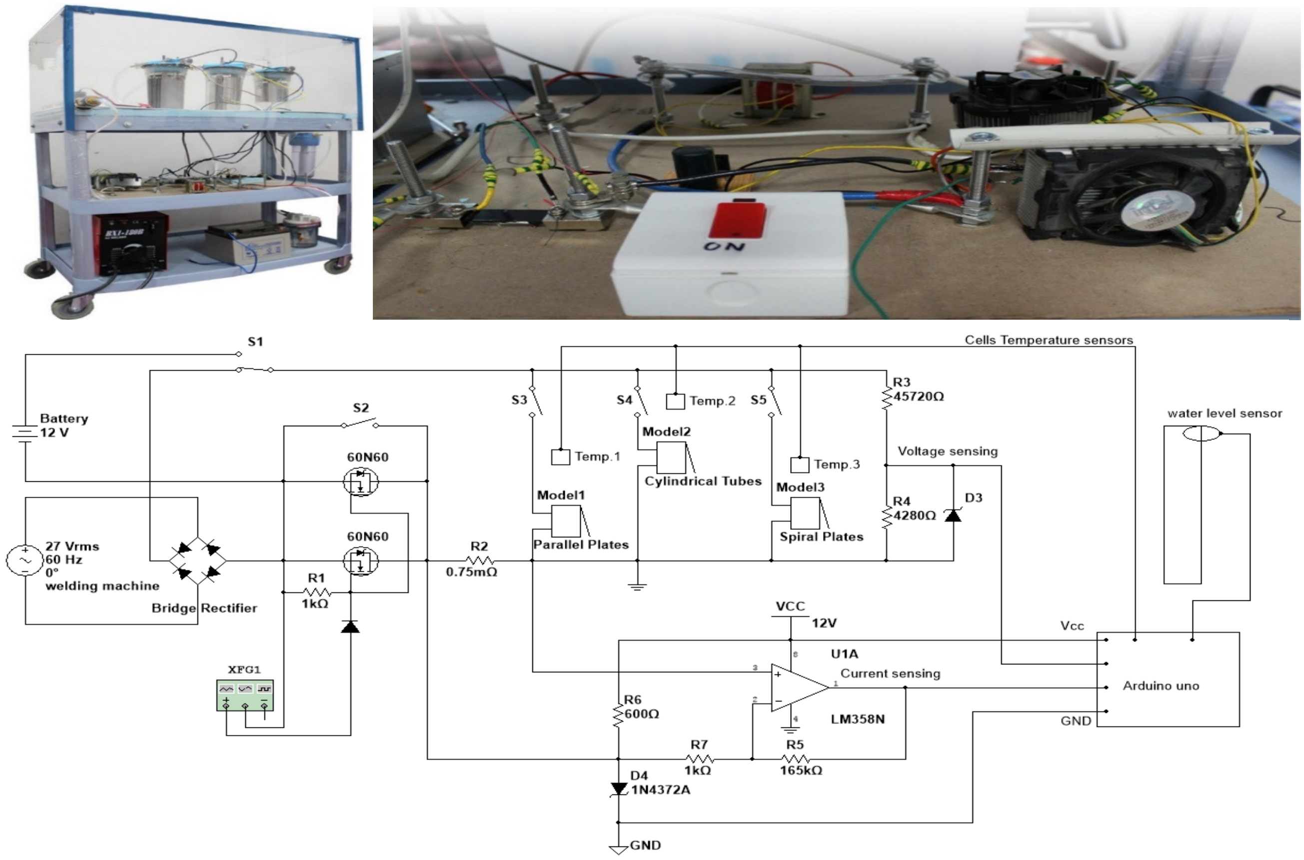

Fig.2. (a) Overall System (b) HHO System implemented Circuit (c) HHO System Circuit.

1.1.Supplies and Shaping circuits.

There are two types of power supplies have been used to provide the system with needed power. Alternating power out from AC Welding machine is used to provide DC power due to its capability of providing over 180 Ampere. In addition, DC power is provided from (LP-12-38 Battery), which can give about 12V and 38A/h.

Fig. 4. (a) AC Welder Machine (b) 12V DC Battery

Fig. 4 shows the two main power sources which have been used to deliver the desired power to the cells for the electrolysis process. Fig. 4(a) shows the AC/DC power supply which used to charge the battery and to supply the circuit with direct and alternating voltage and current. The power supply can give up to 30V and 5A. To control the duty of PWM, a function generator with the capability to vary the duty cycle is required. The function generator provides the freedom to tune the duty cycle to the desired to achieve the required PWM. Also, Fig. 5(b) shows the function generator which used to generate different type of signal with different rang of frequencies for the circuit to shape the DC voltage and produce PWM. Also, analyzing the circuit is an essential technique to verify signal processing through the circuit. Therefore, digital oscilloscope is used evaluate the signal. Finally, Fig. 5 (c) shows the digital oscilloscope which used to sketch the output wave form. Also, it uses for analyzing the output to compare the result with each other.

Fig. 5. (a) DC/AC Power Supply (b) Function Generator– Model AFG 3022B Tektronix (c) Digital Oscilloscope

Also, full wave Rectifier Bridge is one of the AC/DC Converters in which a DC output is targeted from AC input through the Bridge of diodes. Which can handle up to 50Amp. Fig. 6 (a) and (b) shows the bridge rectifier units and bridge rectifier circuit respectively. Chopping the signal is one technique that will be used to generate Pulse Width Modulation signal PWM to investigate the response of such input power. Fig. 6 (c) shows the switching circuit that is used to generate PWM signal. The PWM signal is provided as input power for the HHO cells. The HHO systems consume a lot of current and the switching MOSFET (60N60) cannot handle this current; therefore, we added two MOSFET with heat sink for cooling.

1.2.Power Measurement Circuitry.

To calculate the electric power for each cell, it is needed to measure the voltage across the electrodes of the cell and the current entered to the cell. The voltage for each cell is simply measured across the cell's electrodes. Since that the current is pass through the cells by a small resistor. Fig.7 (a) shows the current and voltage measuring circuit. Also, a small resistor 750μΩ is used to calculate the current entered to the cell. But since the drop voltage across this resistor is too low, the ARDUINO (microcontroller) cannot read it. Fig. 7 (b) shows the resistor which used to calculate the series current

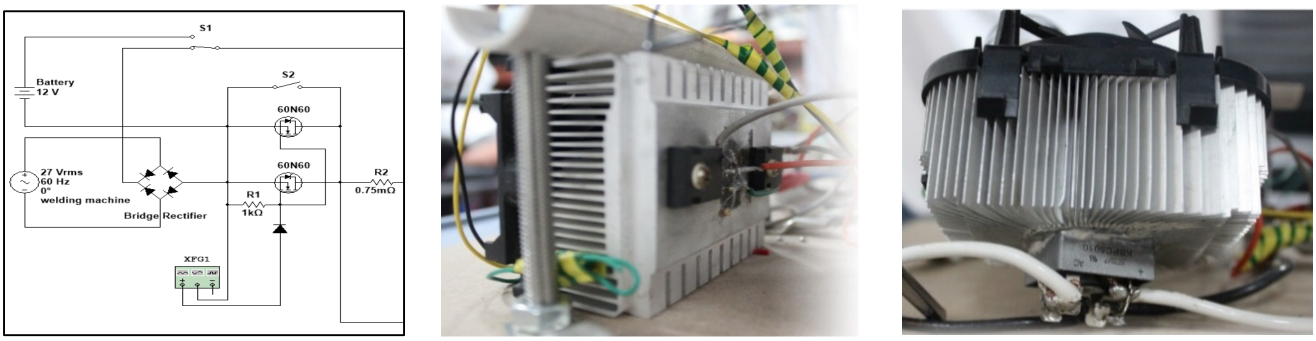

Figure 6: (a) Bridge Rectifier (b) The supplies and chopping circuit (c) the switching circuit to generate PWM signal

Fig. 7. (a) Current and voltage Measuring Circuit (b) 750μΩ Resistor (c) Non-inverting Op-Amp circuit

The maximum Analog Digital Converter (ADC) resolution of ARDUINO UNO is 10bit, which equal to 1023 steps and the supply voltage to Arduino is 5V. Therefore, the minimum current that can be read by ARDUINO directly can be measured as follows:

$$V_{min} = \frac{(\min step)(\max voltage)}{total\ step} = \frac{(1)(5V)}{1023} = 4.9mV$$

$$I_{min} = \frac{V_{min}}{R} = \frac{4.9mV}{0.75m\Omega} = 6.53A$$

Such current values (i.e.6.53A) is considered as huge step and very bad resolution. Therefore, the amplifier must be used to amplifying the signal of the current and increase the resolution. Thus, we have used Non-Inverting Op-amp. The Non-Inverting Op-Amp circuit is given in Fig.7(c). Since Non-Inverting Op-amp with single supply is used, we had to shift up the input signal to avoid the clipping as follows:

$$\boldsymbol{V_{out} = V_{in}A + 0.7} \Rightarrow \boldsymbol{V_{out} = \frac{R_f}{R_{in}} + 1} \quad \text{..... (Equ. 1)}$$

Let's assume that the maximum current flow into the system is 40A, which will generate a drop voltage across the current resister (0.75mΩ) as following:

$$V_{max} = RI_{max} = (0.75m\Omega)(40A) = 30mV.$$

Therefore, the maximum voltage across the resister will be 30mV when the current is 40Amp. When the $V_{in} = V_{max}$ the V_{out} must be equal to 5V. Now, by substituting the values in equ.1 assuming that R_{in}=1.2kΩ, we get the following:

$$5V = 30mV\ A + 0.7 \quad \rightarrow A = \frac{5 - 0.7}{0.03} = 143.3$$

$$\rightarrow 143.3 = \frac{R_f}{1200} + 1 \ \rightarrow \ R_f = 170.8k\Omega$$

Finally, the minimum current that can be sensed by Arduino MCU after the amplification is:

$$I_{min} = \frac{V_{min}}{RA + 0.7} V/((0.75m\Omega)(143.3) + 0.7) = 6.07mA$$

The one step of accuracy of measuring the current has been increased from $6.53A$ to 6.07mA.

1.3.Temperature Measurements Circuitry

For each cell there is a temperature Sensor (DS18B20) is used to measure the internal temperature of the cell. This sensor is waterproof which has been used inside the container to increase the accuracy of temperature sensing. Fig. 8 shows the used temperature sensor.

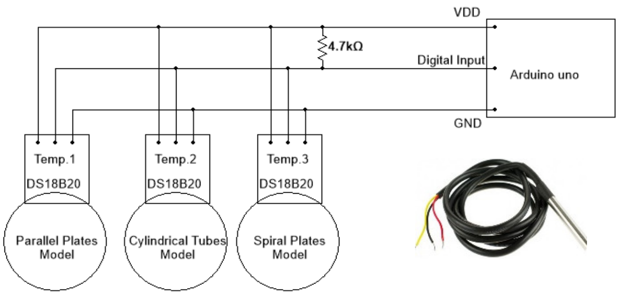

Fig.8. Temperature Sensor and its Circuit

1.4.Control Switches and Valves

The three cells are connected in parallel, and for each time only one cell is working. Thereby, the circuit will be connected in-series through one cell at a time to ensure that the current which measure across the resistor is the one which entered the cell. Also, for each cell, there is a valve to control the flow of HHO gas out of the cell to the bubbler, also to increase the flexibility especially when taken the measurement. Fig. 9 shows the three ON/OFF switches that control the system and the valves that control the gas flow for each cell.

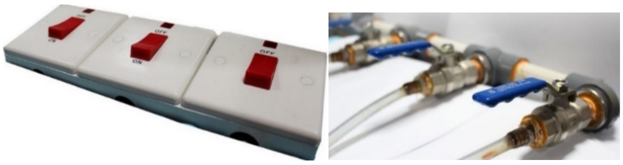

Fig.9. Switches and Valves

1.5.Safety Bubbler

As a safety precaution, a bubbler has been installed to the pipe out of the cells to isolate the produce HHO gas from the cells in case of emergency.

Fig.10. (a) Typical Bubbler (b) Multipurpose bubbler (c) Level tube to calculate amount of gas by ultrasonic sensor

1.6. Actual Models for HHO cells

Three designs have been fabricated to apply the proposed set of experiments targeting the optimum design. Fig. 11 shows (a) the front-view of the three fabricated cells of HHO cell together, (b) Parallel Plates model for HHO Cell, (C) Cylindrical tubes model for HHO Cell, and (d) Spiral Plates model for HHO Cell. Note that the crucial factor is the surface area as the aim of proposed design is to maintain an equivalent surface area for the three models to facilitate a fair comparison and benchmarking between the proposed models to find up the most efficient design. To keep the surface area fixed, it is necessary to choose the right number of plates and the distance between them based on the theoretical calculation.

Fig.11. (a) Alltogother (b) Parallel (c) Cylindrical (d) Spiral.

Note that all the models have been constructed from 304/304L stainless steel material with thickness of 0.5 mm since this type of stainless steel has a higher corrosion resistance and it is widely used because of the ease of shaping as it can be formed into various shapes [14]. However, each model has its own specifications as:

The Parallel Plates Model: This model built up by using ten parallel plate; five plates connected to represent the cathode (negative) and the other five plates representing the anode (positive). Those plates are held together from the top by the head of the container which used to do the electrolysis. Each one of this plate has a dimension of 18 cm length and 7 cm width and the distance between the plates is 5mm. Thus, the total surface area is equal to 1,260 cm^2.

Cylindrical Tubes Model: This model is built up by using four cylinders; two cylinders connected to represent the cathode (negative) and the other two cylinders representing the anode (positive). Those cylinders are held together from the top by the head of the container which used to do the electrolysis. The cylinders have a dimension of 17.5 cm high and 3.8, 5.1, 6.4 &7.6 cm's (1.5", 2", 2.5" &3") diameter and the distance between the cylinders is 5 mm. Thus, the total surface area is equal to 1,260 cm^2.

Spiral Plates Model: This model built up by using two twisted plates, one plate represents the cathode (negative) and the other plate representing the anode (positive). Those plates are held together from the top by the head of the container which used to do the electrolysis. Each one of this cylinder has a dimension of 126cm length and 10cm width and the distance between the plates is 5mm. Thus, the total surface area is equal to 1,260 cm^2.

3 Unit testing and system integration

The complete integrated circuit of the system is illustrated in Fig.12 (a). The control unit controls several processes at the same time, and it controls the signal by high power switching to electrolyze the water. The electric valve controls the flow of water, when the Infrared Ray (IR) transducer detect that the level of water less than the set point (i.e. the pre-specified threshold). The power measuring unit calculates the average power if the power supply had been used; otherwise, it will calculate the apparent power. Thereafter, to ensure accurate verification and precise validation for system functionalities, we have conducted considerable number of experiments for each single design model to analyze the effectiveness of hydrogen oxygen gas production out of each cell. These experiment sets are categorized into two major categories: Experiments using DC power out from a battery and Experiments using DC power out from AC Welding Machine to supply high current. Also, we have used two types of water to investigate the efficient type of water, pure distilled water and distilled water with acid. Furthermore, two options are provided as an external catalyst for the electrolysis. Figure12 (b) shows the experiment set that will be applied for the three design cells: Parallel Plate, Cylindrical and Spiral. According to the figure, different power source is supplied: the battery is used to provide and maintain certain DC level, which is pure DC supplied from the battery while AC Welding Machine will be used to produce DC Power via full bridge diode. The supplied power (either from the battery or AC Welding Machine through full wave rectifier) is modulated using Pulse Width Modulation (PWM) for different Duty cycle such as 25%, 50% and 75% of the used AC power. The used frequency is 1 kHz (25%, 50% and 75% of duty cycle), 10 kHz (50% of duty cycle), 50 kHz (50% of duty cycle) and 100 kHz (50% of duty cycle). What distinguish the DC output of the battery from the DC output of the AC Welding Machine is that the output DC of the battery has no ripples while the other has ripples. Sulfuric acid ($\mathbf{H_2SO_4}$) is used to increase the conductivity of water to enhance the electrolysis process. In coming part, we will provide several figures that demonstrates the results of the steps of the experimental measurements. The summary of experimental results is given in Table I. We have plotted all results in the table via MATLAB to analyze and study the behavior of different relationships as shown in the set of Figures (12-29). Fig.13 shows the relationship between the level of HHO per Energy with respect to frequency change. Its observed that the distilled water with acid generate more HHO gas by the same energy; on other said, the pure distilled water generates less HHO gas by the same energy at low frequencies. Moreover, the distilled water with acid is more affected by low frequency, since it has more conductivity than the pure distilled water.

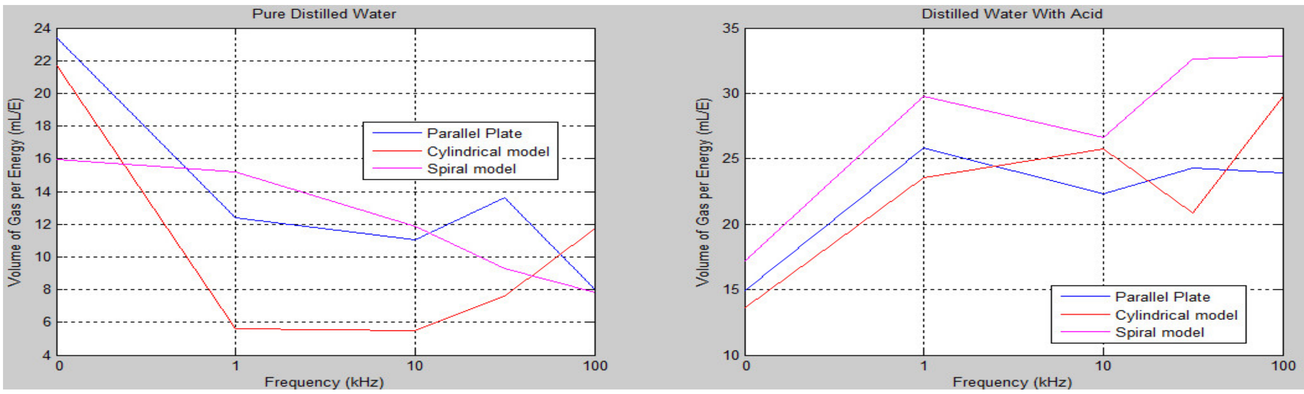

Fig.13. Level of HHO per Energy vs Frequency.

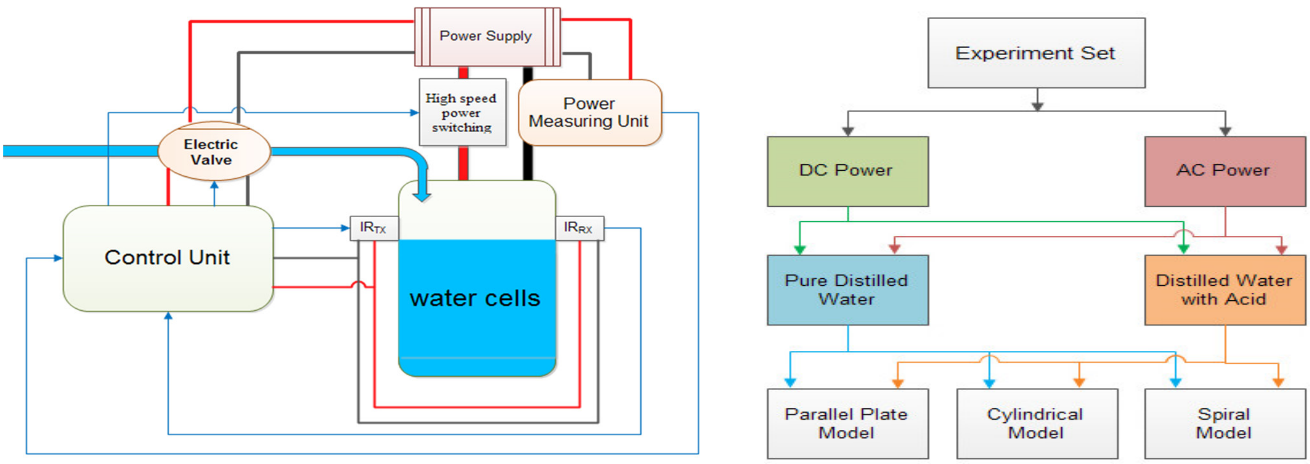

Fig. 12. (a) System's Integrated circuit (b) Experiment Set chart.

Table 2: Experimental Sets for The Three Models Using Two Types of Water and Two Different Voltage Sources

Pure Distilled Water							
	Voltage Type	**Freq/ Duty cycle**	**dtime (S)**	**dLevel (mL)**	**dT**	**Energy (kJ)**	**dl/E**
parallel plates	DC		641.70	113	1.5	4.8342506	23.374874
	AC	1kHz 25%	818	6	0.06	1.3497	4.445432
		1kHz 50%	303	15	0.12	1.212	12.37624
		1kHz 75%	573	110	0.62	3.990945	27.56239
		10kHz	151	20	0.13	1.812	11.03753
		50kHz	1065	30	0.06	2.20455	13.60822
		100kHz	781	15	0.06	1.8744	8.002561
Cylindrical Tubes	DC		991.32	103	0.81	4.752337	21.673547
	AC	1khz 25%	2422	50	0.5	2.71264	18.43223
		1khz 50%	3300	60	0.87	10.692	5.611672
		1khz 75%	425	45	0.32	2.295	19.60784
		10khz	593	15	0.25	2.73966	5.475132
		50khz	423	10	0.13	1.312146	7.621103
		100khz	655	10	0	0.8515	11.74398
Spiral Plates	DC		1596.60	105	1.75	6.568489	15.985412
	AC	1khz 25%	1179	45	0.42	2.5938	17.34906
		1khz 50%	763	65	0.43	4.2728	15.21251
		1khz 75%	349	44	0.44	3.26664	13.4695
		10khz	871	55	0.63	4.638075	11.85837
		50khz	366	15	0	1.61406	9.293335
		100khz	400	20	0.19	2.56	7.8125
Distilled Water with Acid							
	Voltage Type	**Freq/ Duty cycle**	**dtime (S)**	**dLevel (mL)**	**dT**	**Energy (kJ)**	**dl/E**
parallel plates	DC		19.00	90	0.75	6.0401	14.90041556
	AC	1kHz 25%	48.26	45	0.25	1.455039	30.92701
		1kHz 50%	38.66	70	0.37	2.711999	25.81122
		1kHz 75%	40.78	87	0.32	5.187216	16.772
		10kHz	44.21	35	0.19	1.570339	22.28818
		50kHz	43.38	23	0.06	0.947419	24.27648
		100kHz	50.85	23	0.37	1.043442	23.95917
Cylindrical Tubes	DC		11.66	40	0.69	2.936571	13.621329
	AC	1khz 25%	47.66	28	0.44	1.388812	20.16111
		1khz 50%	31.96	49	0.31	2.0774	23.58718
		1khz 75%	20.18	43	0.25	2.233926	19.24862
		10khz	43.83	35	0.25	1.35873	25.75935
		50khz	35.55	20	0.06	0.95985	20.83659
		100khz	32.48	20	0.06	0.672336	29.74703
Spiral Plates	DC		15.05	95	0.81	5.5295205	17.180513
	AC	1khz 25%	53.8	70	0.31	2.276816	30.74469
		1khz 50%	29.59	70	0.32	2.351221	29.77176
		1khz 75%	22.21	65	0.22	2.92639	22.21167
		10khz	39.96	55	0.06	2.06793	26.59664
		50khz	23.64	20	0.03	0.612749	32.6398
		100khz	26.05	20	0.02	0.608528	32.8662

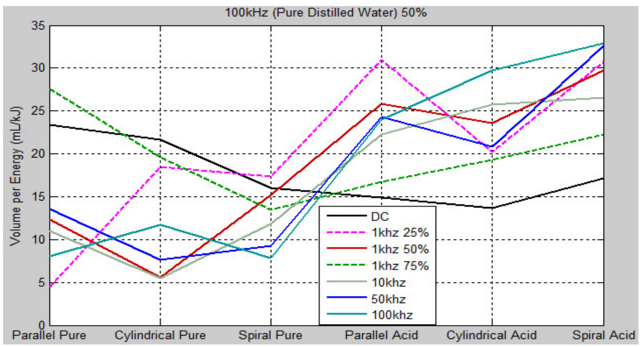

Fig.14. HHO volumes per Energy for the three models

Figure 14 shows the relationship between the volume of HHO per Energy with respect to three designs with acid and without. It can be observed that the applied DC voltage is almost efficient than AC voltage of pure distilled water for the three designs. However, the applied DC voltage has the least efficiency comparing with AC voltage of distilled water with acid for the three designs. Figures (15-28) are clearly plotted with respect to time for different design models (parallel, cylindrical, spiral), different parameters (volume, temperature), different frequencies (1kHz, 10kHz, 50kHz, 100kHz) and different PWM duty cycles (25%, 50%, 75%). They can be summarized as follows:

- Figure.15 shows the volume of HHO with respect with time using DC power.
- Figure.16 shows the volume of HHO with respect to time for 1kHz using PWM with 25% duty cycle.
- Figure.17 shows the volume of HHO with respect to time for 1kHz using PWM with 25% duty cycle.
- Figure.18 shows the volume of HHO with respect to time for 1kHz using PWM with 25% duty cycle.
- Figure.19 shows the volume of HHO with respect to time for 10kHz using PWM with 50% duty cycle.
- Figure.20 shows the volume of HHO with respect to time for 50kHz using PWM with 50% duty cycle.
- Figure.21 shows the volume of HHO with respect to time for 100kHz using PWM with 50% duty cycle.
- Figure.22 shows the cell temperature with respect to time for DC power.
- Figure.23 shows the cell temperature with respect to time for 1kHz using PWM with 25% duty cycle.
- Figure.24 shows the cell temperature with respect to time for 1kHz using PWM with 50% duty cycle.
- Figure.25 shows the cell temperature with respect to time for 1kHz using PWM with 75% duty cycle.
- Figure.26 shows the cell temperature with respect to time for 10kHz using PWM with 25% duty cycle.
- Figure. 27 shows the cell temperature with respect to time for 50kHz using PWM with 50% duty cycle.
- Figure. 28 shows the cell temperature with respect to time for 100kHz using PWM with 50% duty cycle.

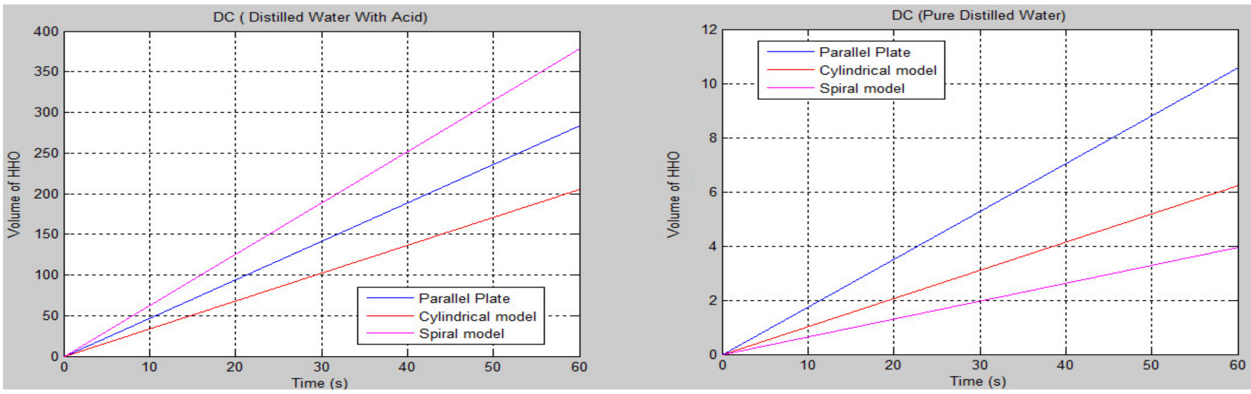

Figure 15. Volume of HHO with respect to Time for DC Power.

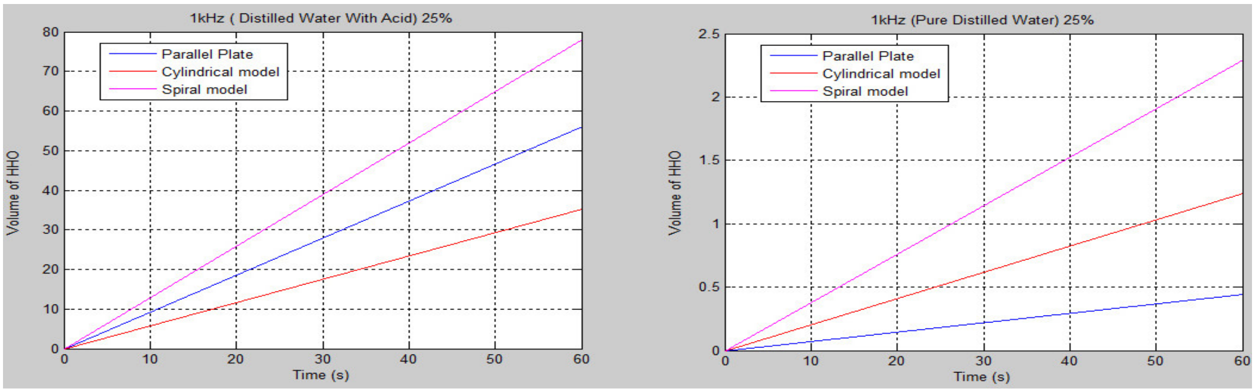

Figure 16: Volume of HHO with Respect to Time for 1kHz PWM of 25% Duty Cycle.

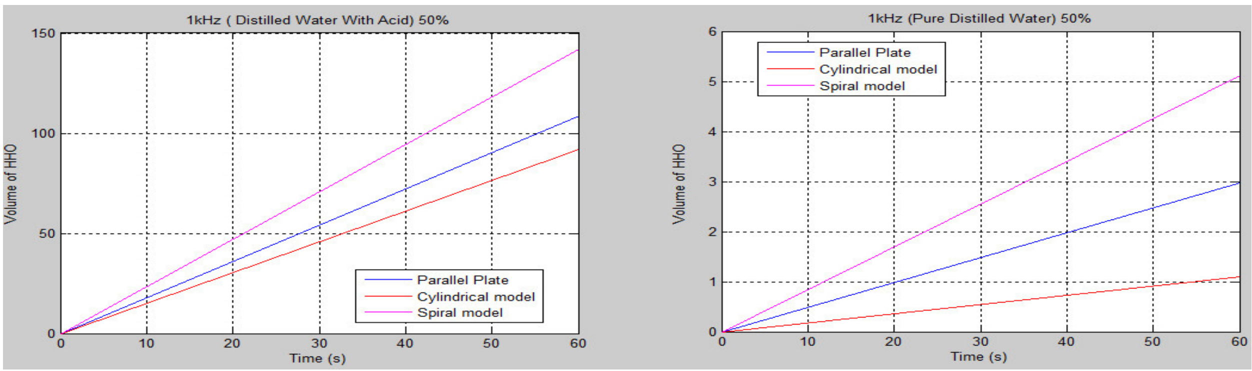

Figure 17: Volume of HHO with Respect to Time for 1kHz PWM of 50% Duty Cycle.

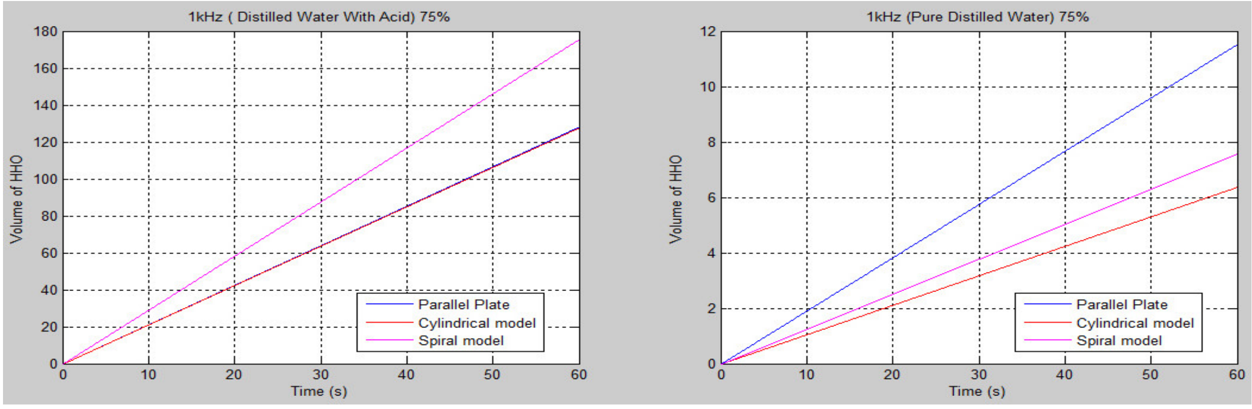

Figure 18: Volume of HHO with Respect to Time for 1kHz PWM of 75% Duty Cycle.

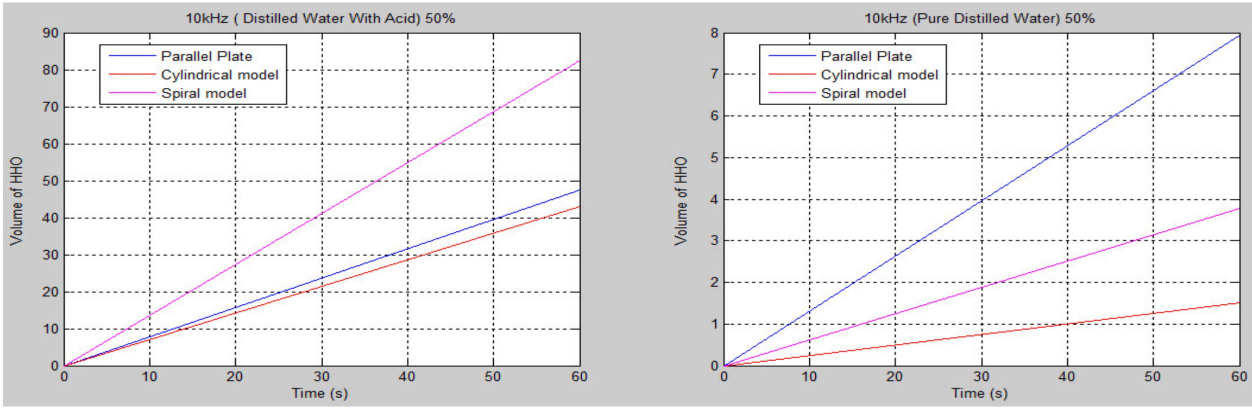

Figure 19: Volume of HHO with Respect to Time for 10kHz PWM of 50% Duty Cycle.

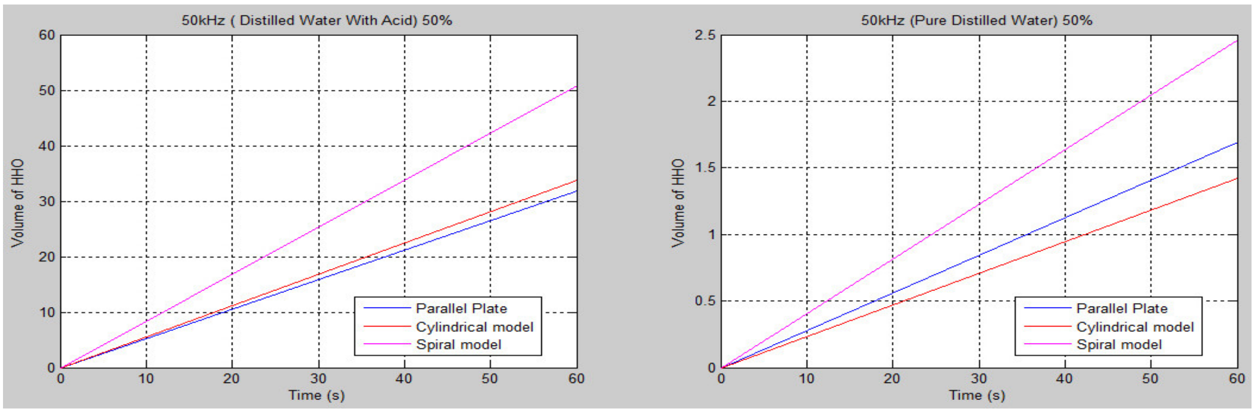

Figure 20: Volume of HHO with Respect to Time for 50kHz PWM of 50% Duty Cycle.

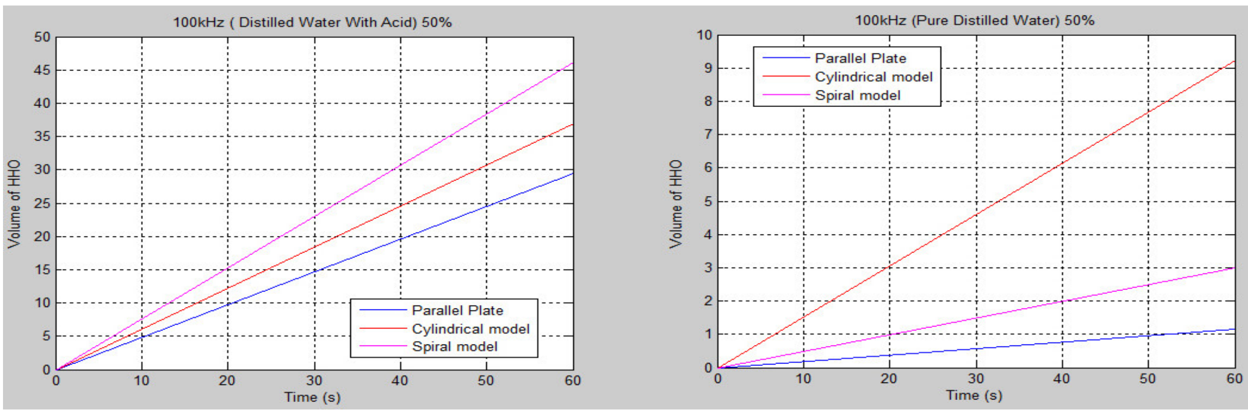

Figure 21: Volume of HHO with Respect to Time for 100kHz PWM of 50% Duty Cycle.

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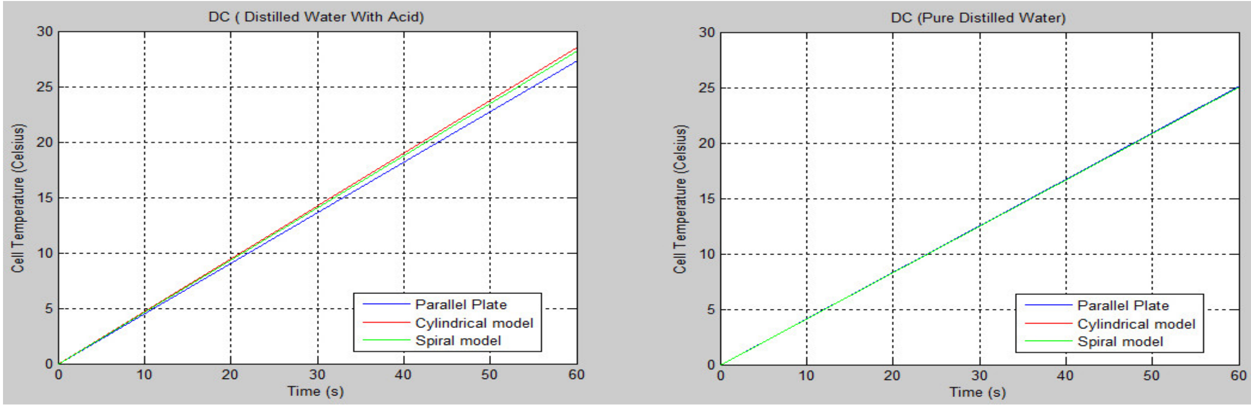

Figure 22: Cell Temperature with Respect to Time for DC Power.

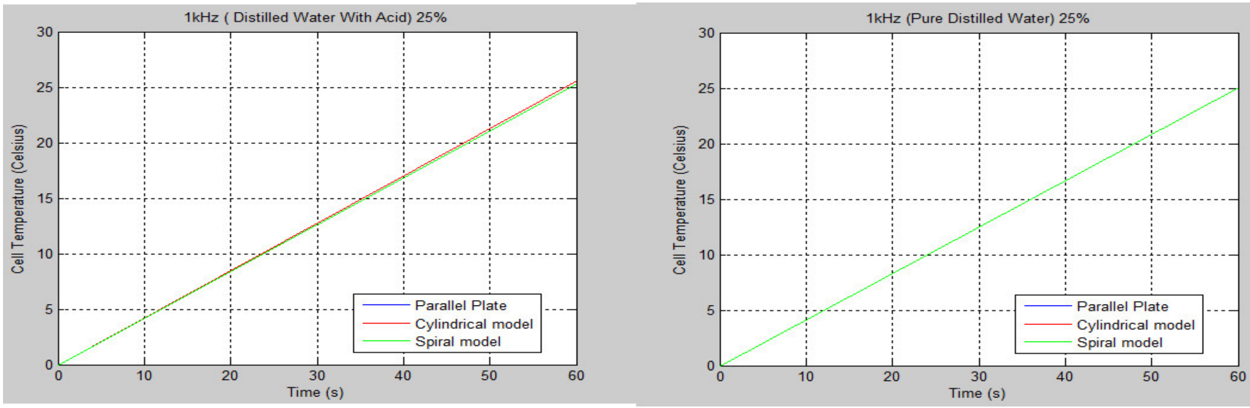

Figure 23: Cell Temperature with Respect to Time for 1kHz PWM of 25% Duty Cycle.

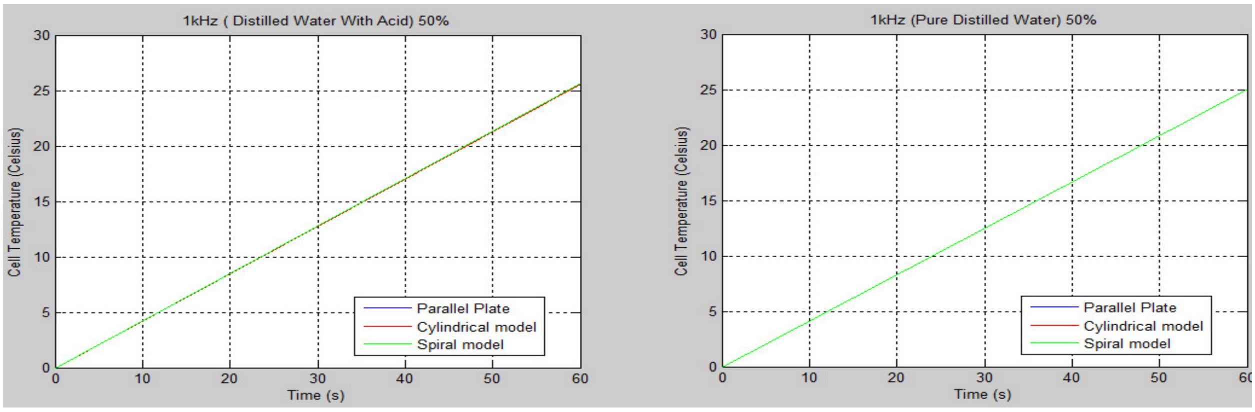

Figure 24: Cell Temperature with Respect to Time for 1kHz PWM of 50% Duty Cycle.

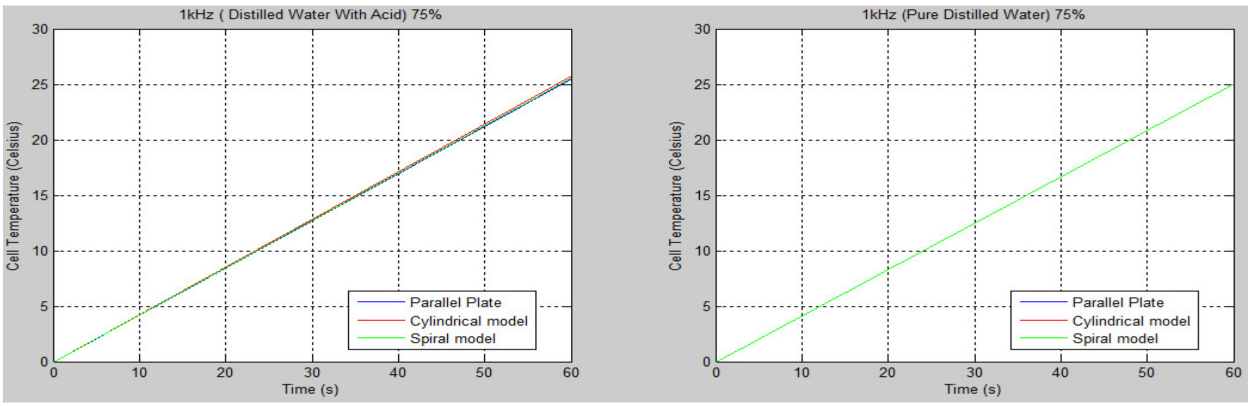

Figure 25: Cell Temperature with Respect to Time for 1kHz PWM of 75% Duty Cycle.

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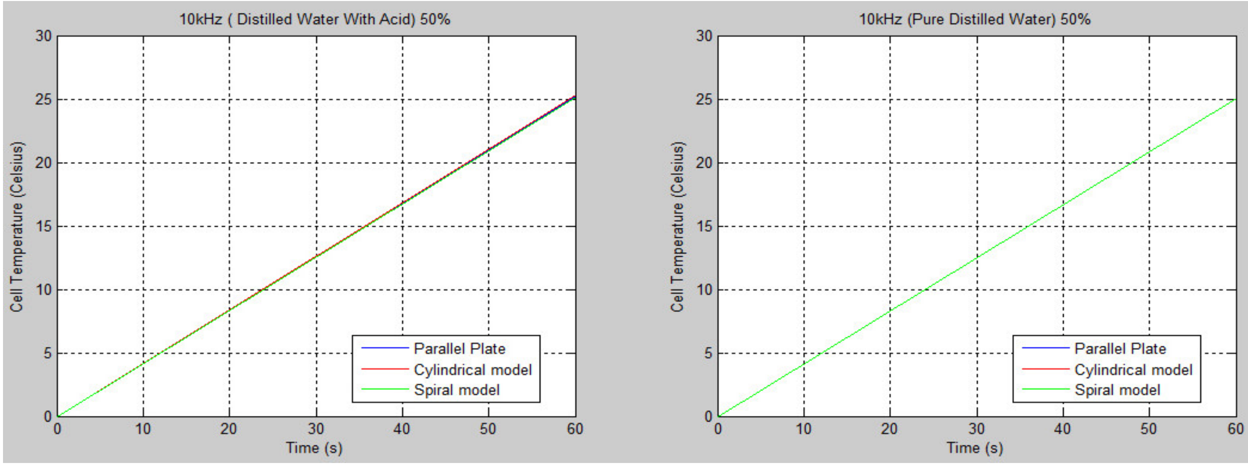

Figure 26: Cell Temperature with Respect to Time for 10kHz PWM of 50% Duty Cycle.

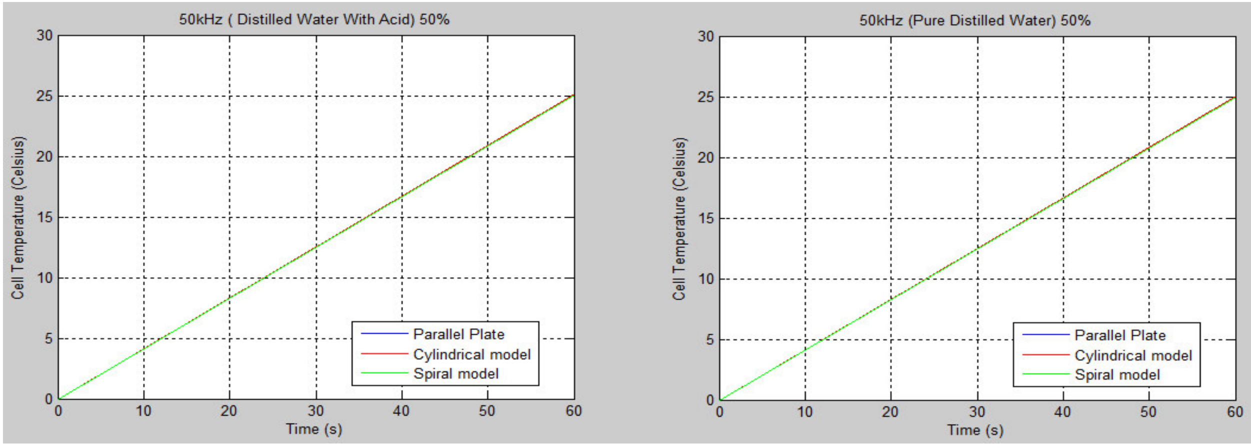

Figure 27: Cell Temperature with Respect to Time for 50kHz PWM of 50% Duty Cycle.

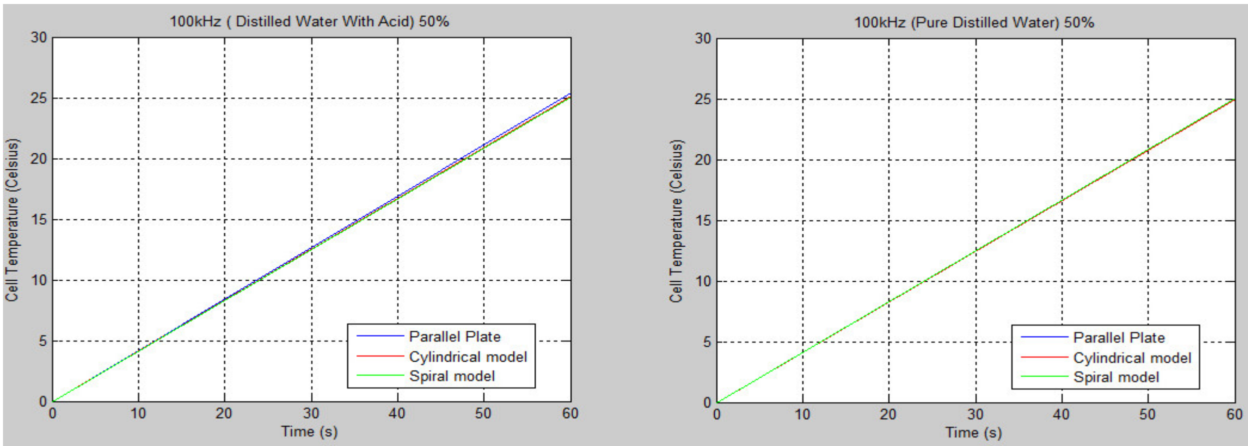

Figure 28: Cell Temperature with Respect to Time for 100kHz PWM of 50% Duty Cycle.

Finally, Figure.29(a) shows the practical setup for the experiment with the presence of light. Where it is investigated wither, there will be an effect of light on the electrolysis process or not. This experiment is to investigate if there is an effect from the light on the amount of HHO released, but through the experiment it has been noted that the more effect came from the temperature of the light. Fig.29(b) shows the volume of gas per energy and the cell temperature are the measurement target to investigate if there is an effect of the presence of light. The figure shows Volume of Gas per Energy and the cell temperature for three runs. The first two have been done at the same initial temperature 31℃, one of them with light and the second without light, where the third one was without light and it started at 23.81℃. It has been noticed that for the high temperature experiments the HHO released are more than the low temperature.

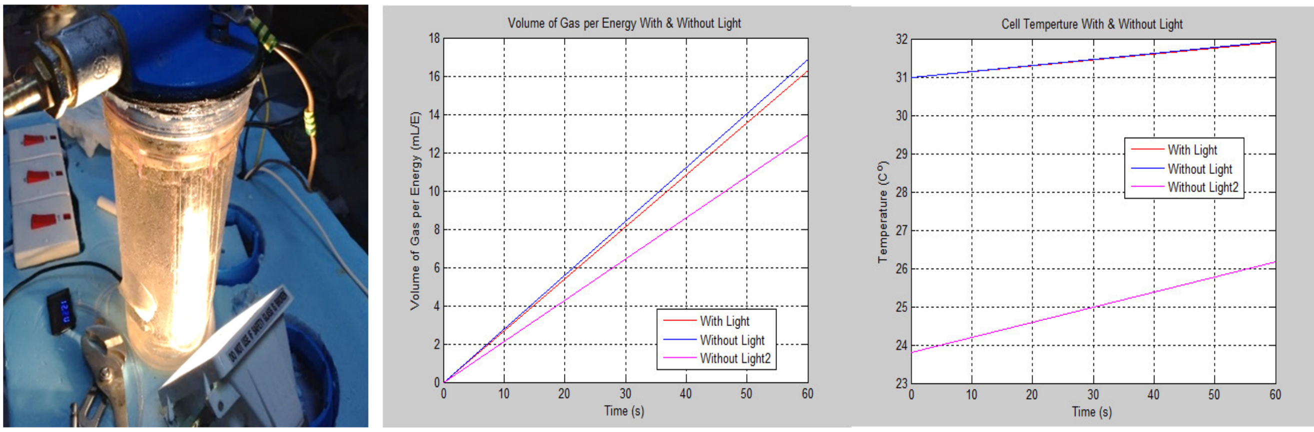

Figure 29: (a) Light Experiment Setup (b) DC voltage is supplied to the parallel plate model for investigation.

4 Conclusion and Remarks

In this paper, the photovoltaic system is considered as the renewable energy source and HHO cell is sub-system replacement for the energy storage system batteries. HHO cells have overcome many of the batteries' problems such as environment impact, reliability, pollution, cost and feasibility. Thus, three design alternatives have been proposed for the internal plates (Parallel, Cylindrical, Spiral) each of which can be modeled into electric circuit to calculate the plates parameters i.e. resistance, inductance and capacitance. Accordingly, this work can be extended to cover up the mathematical modeling and comparison to determine the optimum design in addition to the hardware design implementation as well as the design benchmarking and evaluations. In term of design safety, several actions have been proposed to ensure the safety of the system. To isolate the produced gas from the system a bubbler has been suggested for isolation. In order to maintain fixed water level, an electric valve controlled by sensors on the water container will be installed. Moreover, a plexiglass box will be used to contain the system as a precaution for any further action. Finally, hydrogen sensor will be installed to detect hydrogen gas leakage. The complete design cost practically 1200 USD which means reduced the expected cost by 26 %.

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