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Effect of Electrodes' Geometry on Hydrogen and Oxygen Production Using PV Powered Water Electrolyzing System

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Abstract

Water electrolysis is an efficient method for producing hydrogen and oxygen by splitting water. The electrolyzer splits water into hydrogen and oxygen when two electrodes are immersed in that water and then an electric current passes between those two electrodes. The two electrodes are separated by non-electrical conducting material such as resistive Teflon. The production efficiency depends on important design variables such as the electrodes' geometry. This work presents an experimental study that is conducted to investigate effect of the electrodes' geometrical parameters: height and shape and effect of the gap between the two electrodes on hydrogen production. The experimental results shows that the production of hydrogen and oxygen increases as the height of the electrodes increases in both cylindrical and flat plate shaped electrodes. In addition, the gap between the two electrodes affects the production where having smaller gap causes production to increase.

Keywords: water electrolyzer, hydrogen and oxygen production, electrodes' geometry, Photovoltaic

INTRODUCTION

Due to the depletion of traditional energy resources, such as crude oil, natural gases, and coal many initiatives all over the world have addressed the efficient use or otherwise the replacement of these resources [1]- [4]. Several renewable energy resources have been introduced as replacement; which helps protecting the environment and improving quality of life. Utilizing renewable energy promises a bright future for humanity because it uses a clean, and sustainable fuel [5][6]. Electrical energy production using photovoltaic systems is very important issue for renewable energy [7]. One of the most important drawbacks of using photovoltaic systems is the difference in illumination of the sunlight throughout the daytime and the absence of solar radiation at night time [8][9]. Therefore, to efficiently use the electrical energy produced by photovoltaic modules, it is necessary to store this energy or otherwise convert it into high energy materials, such as hydrogen and oxygen gases [10]- [12]. One of the methods to produce hydrogen is using water electrolysis where electric current passes through water resulting in splitting water into hydrogen and oxygen [13]- [16]. The hydrogen stores electrical energy, and it can be used to generate electricity in a fuel cell by a process that is the reverse of electrolysis [17]. A life cycle assessment of the processes indicates that it has minimal environmental burden [18] [19], but at the same time it incorporates quite considerable savings [20]- [22].

Recently, many researchers from different countries suggested hydrogen to be considered as one of the most important high energy materials [23]- [26]. Many researchers such as Rossi et al. [27], Ben Slama [28] and Abdallah et al. [29]built an experimental facility to investigate how to improve the hydrogen production by water photo-electrolysis. Furthermore, many researchers built simulation models to optimize hydrogen production. In [30]Ziogou et al. simulated system performance criterion incorporating efficient and economic operation of a hydrogen production unit through water electrolysis with solar power. Rivera-Tinoco et al. [31]used simulation to estimate the process investment and operation costs of hydrogen production process. Furthermore Buddhi et al. [32]conducted a sensitivity analysis of the electrolysis system to examine the effect of total dissolved solids on the hydrogen production rate.

Many design parameters were investigated in the literature such as the effect of TDS (Total Dissolved Solids) [33] , and the effect of PH levels [34]. In addition, Mahrous et al. [35]and Chennoufa et al. [36]investigated the effect of input voltage amplitude. Suffredini et al [37] investigated different types of electrodes. They noticed that for alkaline water electrolysis anode made of mixed Ni-Co oxides with a spinal structure and cathode made of Ni-based alloys either amorphous or crystalline will enhance the electrolysis process. This work aims to investigate the effect of electrodes' geometrical parameters such as height and shape and gap between the inner and outer diameter on the hydrogen and oxygen production.

EXPERIMENTAL DESIGN OF SYSTEM

In purpose of investigating the effect of electrodes' geometry on the hydrogen and oxygen production, testing electrolyzing cells are built. A schematic diagram of water electrolyzer, used in this work, is presented in Figure 1 and Figure 2. Each system consists of water electrolyzer, photovoltaic generator, hydrogen and oxygen measurement instrument, and bubbler. The description of each element of this system can be described as following:

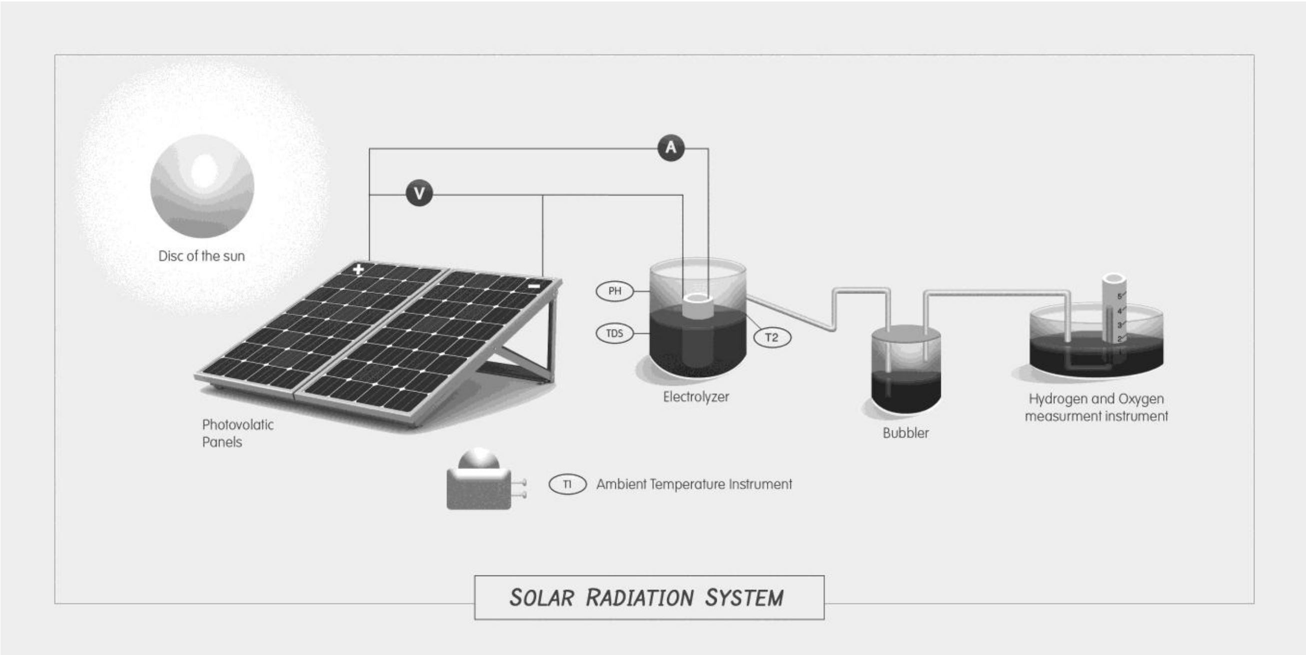

Figure 1: Schematic Diagram of photovoltaic powered water electrolyzer with cylindrical shaped electrodes.

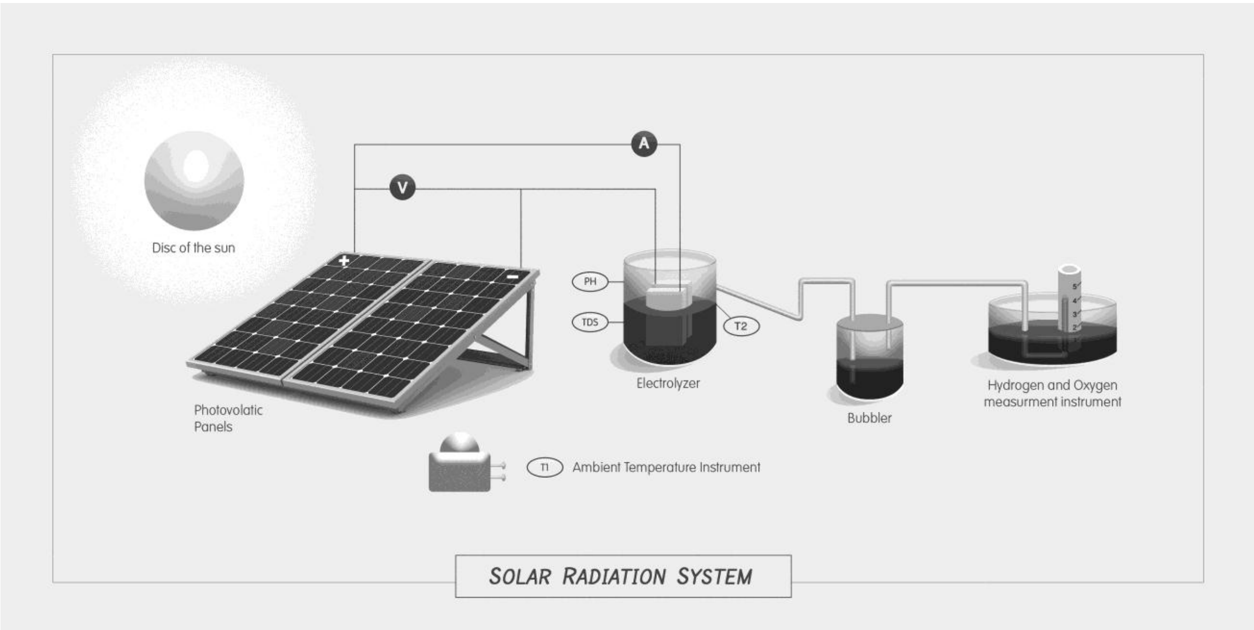

Figure 2: Schematic Diagram of photovoltaic powered water electrolyzer with flat plate shaped electrodes

A) Photovoltaic power generator.

A photovoltaic array consisting of PV panels is used to generate electrical power supply in this system. The array is placed on a fixed mechanical base with 11° inclination directed to the south as shown in

Figure 3. The main technical specifications of each photovoltaic panel are: Nominal maximum output power = 40 W, Nominal maximum output current = 2.34 A, Nominal maximum output voltage=16.9V, and Nominal mass = 4.5 Kg.

Figure 3: Photovoltaic modules

B) Water electrolyzer.

Water electrolyzer consists of cylindrical plastic container as shown in Figure 4 . Inside the electrolyzer there will be two electrodes. The electrodes are made of stainless steel 316. Each electrode is welded to a 316 stainless steel rod to make an easy contact with the power supply. In this work, electodes with two different shapes are used: cylindrical shaped electrodes and flat plate electrodes. In the first case, electrodes are two cylinders with the same height, but with different diameters, one is inserted into the other as shown in Figure 5. They operate as a cathode and an anode. For the latter case, the two electrodes are flat plate shape, with specific dimensions which are: height, width and thicknesses, shown in Figure 6. The flat plates electrodes are separated by a gap which is filled with a non-electrical conducting material which is resistive Teflon.

At the beginning of each experiment, the electrolyzer is filled with water. Then, the electrodes are immersed in the water and connected to the terminals of photovoltaic array. An electrical current starts to flow through the system and it can be observed that the reaction has begun. Hydrogen appears at the cathode (the negatively charged electrode) and oxygen appears at the anode (the positively charged electrode). Hydrogen and oxygen flow through a pipe to the bubbler and from there to the production measuring device.

Figure 4 : Water electrolyzer

Figure 5: Cylindrical shaped electrode

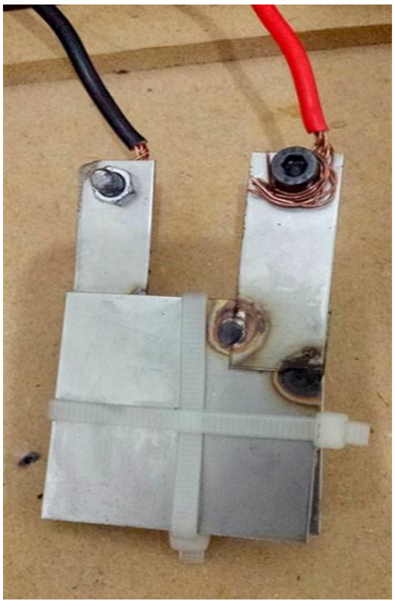

Figure 6: Flat plate electrode

C) Bubbler.

The bubbler is a cylindrical shape device which prevents the reverse of hydrogen and oxygen flow for safety and production purposes.

D) Hydrogen and oxygen measurement instrument.

In order to measure the quantity of gas produced by the reaction, a home-made instrument is prepared. The gas produced is gathered inside a cylindrical plastic container. This plastic container is connected to the electrolyzer (the gas source) through a bubbler. Before being used, this container is filled with water and then it is being turned upside down inside a scaled bucket; the scale on the bucket is marked every 0.5 liter. As the gas bubbles in, it pushes the water into the bucket. The water level in the bucket is the volume of gas produced.

EXPERIMENTAL WORK AND RESULTS

This section includes the instrumentation used in the experiments, the experimental work and setup, and the experimental results.

Instrumentation

In this work, different electronic measuring devices and instruments are used; but before being used they were tested and calibrated.

Pyranometer : use to measure the global solar radiation on the horizontal surface. This Pyranometer has a sensitivity of 16.52 μV/W/m^2.

Calibrated thermocouple (type-K) coupled to a digital thermometer: used to measure the water temperature inside electrolyzer. The range of measurement for this thermometer is from -199.9 to 137℃ and its accuracy is $\pm$ 1℃ .

Clamp meter: used to measure the electric current which goes through a conductor. The range of measurement for this instrument is from 0 to 20 A. The accuracy of ammeter is $\pm$ 3%.

Voltmeter: use to measure the voltage. The range of measurement for this instrument is from 0 to 40 V and the accuracy of the instrument is $\pm$ 4%.

TDS tester: used to measure the concentration of total dissolved solids in water or TDS. The range of measurement for this instrument is from 0 to 5000 ppm and its accuracy is $\pm$2%.

PH tester: used to measure the level of acidity and alkalinity of water. The range of measurement for this instrument is from 0 to 14 PH. The accuracy is $\pm$ 0.01 PH and the resolution is 0.01 PH and.

Experimental setup

At the beginning of each experiment, the electrolyzer is filled with water of 458 TDS and 7 PH and the electrodes are fully immersed in water and then the terminals of the solar panels are connected to the electrodes. In the following sections, the experimentation is divided into three parts to study the effect of gap between electrodes as well as electrode's geometry on the hydrogen and oxygen production.

Part one: Effect of electrodes gap on hydrogen and oxygen production

Four identical experimental setups are used in this part. The Water electrolyzer consists of cylindrical plastic container which has 30 cm height, a diameter of 11 cm and a 1.5 liters of water capacity.

The four electrolyzers uses cylindrical electrodes with different gap between the outer electrode and the inner electrode; the gap values are 2 mm, 9 mm 13 mm and 20 mm. The four electrodes has height of 18 cm and thickness 2 mm. But they differ in the outer and inner diameters where they are 8.1 cm and 7.3 cm, 7.7 cm and 5.5 cm, 6.8 cm and 3.8 cm, 7.2 cm and 2.8 cm for the 2 mm, 4 mm, 9 mm and 13 mm gaps respectively.

Part two: Effect of cylinder height on hydrogen and oxygen production

Four identical experimental setups are used in this part. Water electrolyzer consists of cylindrical plastic container which has 30 cm height, a diameter of 11 cm and a 1.5 liters of water capacity.

In each electrolyzer, the two electrodes are cylindrical shape. The outer electrode is 3.11 cm diameter and the inner electrode is 2.95 cm diameter; thus the gap between the two electrodes is 16 mm. The thickness is 3 mm. In this part, each cell has a cylindrical electrode with certain height: 5cm, 10cm,15cm or 20cm while the other specifications are the same for the all electrolyzers.

Part three: effect of flat plate height on hydrogen and oxygen production

Four identical experimental setups are used in this part. Water electrolyzer uses a cylindrical plastic container with 40cm height, 12 cm diameter, and 2 liters of water capacity.

In each electrolyzer, the two electrodes are flat plate shape. The width of each plate is 5cm, the thickness of each plate is 1.5 mm and the gap between the two plates is 5 mm. In this part, each cell has a flat plate shaped electrodes with certain height: 4cm, 5cm, 6cm and 7cm while the other specifications are the same for all electrolyzers.

Experimental results.

This section presents the results of experimentation. Results for the three experimental parts are shown in Figure 7 , Figure 8 and Figure 9. The figures show the following quantities as a function of time: solar radiation, ambient temperature, solution temperature inside the electrolyzer, electrical current, electrical voltage and hydrogen and oxygen production. In general, hydrogen and oxygen production increases during the day until it reaches maximum yield around mid-noon. Then, the yield decreases as the sunsets. The highest current and voltage produced by the PV modules are maximized at mid-noon which is characterized by maximum solar radiation and maximum ambient temperature. This also affects the solution temperature, which is maximum at mid-noon. In general, the solution temperature is high for the cases when the current is high. This is clearly shown in Figure 7 and Figure 9. Nevertheless, for Figure 8, which studies the effect of electrode height, it shows that the solution temperature is higher in case of 5cm compared to that of 20cm which has the highest current. This behavior can be explained by the fact that as the electrode height increases, the water volume needed to fully immerse the electrodes increases. As the water volume increases, the temperature will be dissipated in larger volume of water.

To conclude the effect of geometrical parameters on hydrogen and oxygen production, the production gain is calculated for the three experimental parts. Production gain is calculated based on the total hydrogen and oxygen production per day as follows:

$$\text{Production gain} = \frac{p_p - p_s}{p_s} * 100\%$$

Where:

p_s: total hydrogen and oxygen production per day for the base case

p_p: total hydrogen and oxygen production per day for the rest of the cases

Production gain is shown in figure 7. for the three experimental parts. It is clear that the productivity increases as the gap between cylindrical electrodes decreases. In addition, as the height of the cylindrical electrode increases the productivity increases. Moreover, the production increases with the increase in height in case of flat plate electrodes.

Table 1: Production gain for the three experimental parts.

Part 1: effect of gap between two cylindrical electrodes	Geometry	20mm	13mm	9mm	2mm
	Production	11.05	14.78	22.38	26.60
	Gain	Base case	33.8%	102.5%	140.7%
Part 2: effect of height in case of cylindrical electrodes	Geometry	5cm	10cm	15cm	20cm
	Production	26.65	28.95	31.1	33.4
	Gain	Base case	8.6%	16.7%	25.3%
Part 3: effect of height in case of falt plate electrodes	Geometry	4cm	5cm	6cm	7cm
	Production	18.1	23.6	26.2	25.6
	Gain	Base case	30.4%	44.8%	41.4%

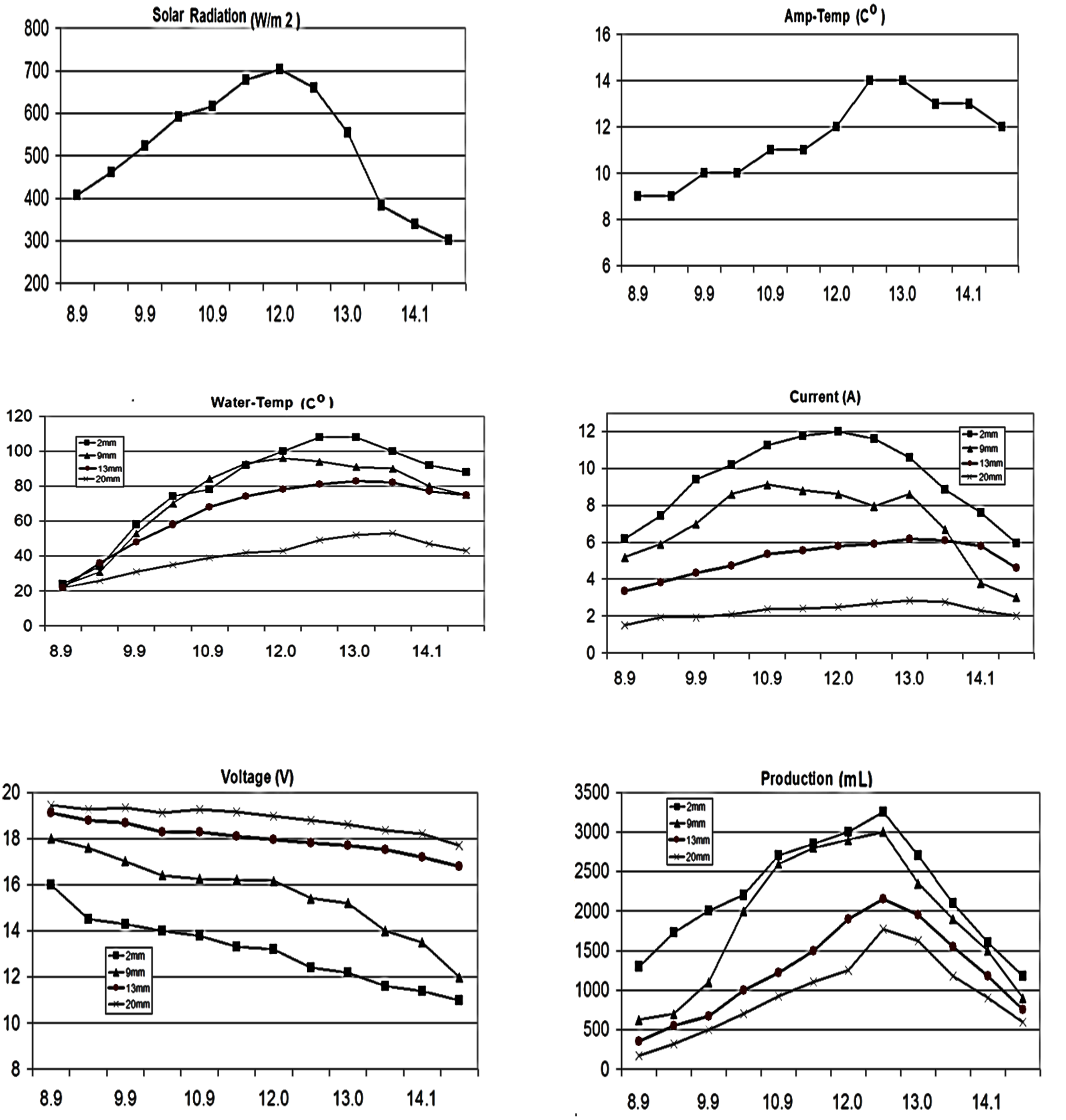

Figure 7: Part one effect of gap between outer and inner diameter of cylindrical electrodes on hydrogen and oxygen production

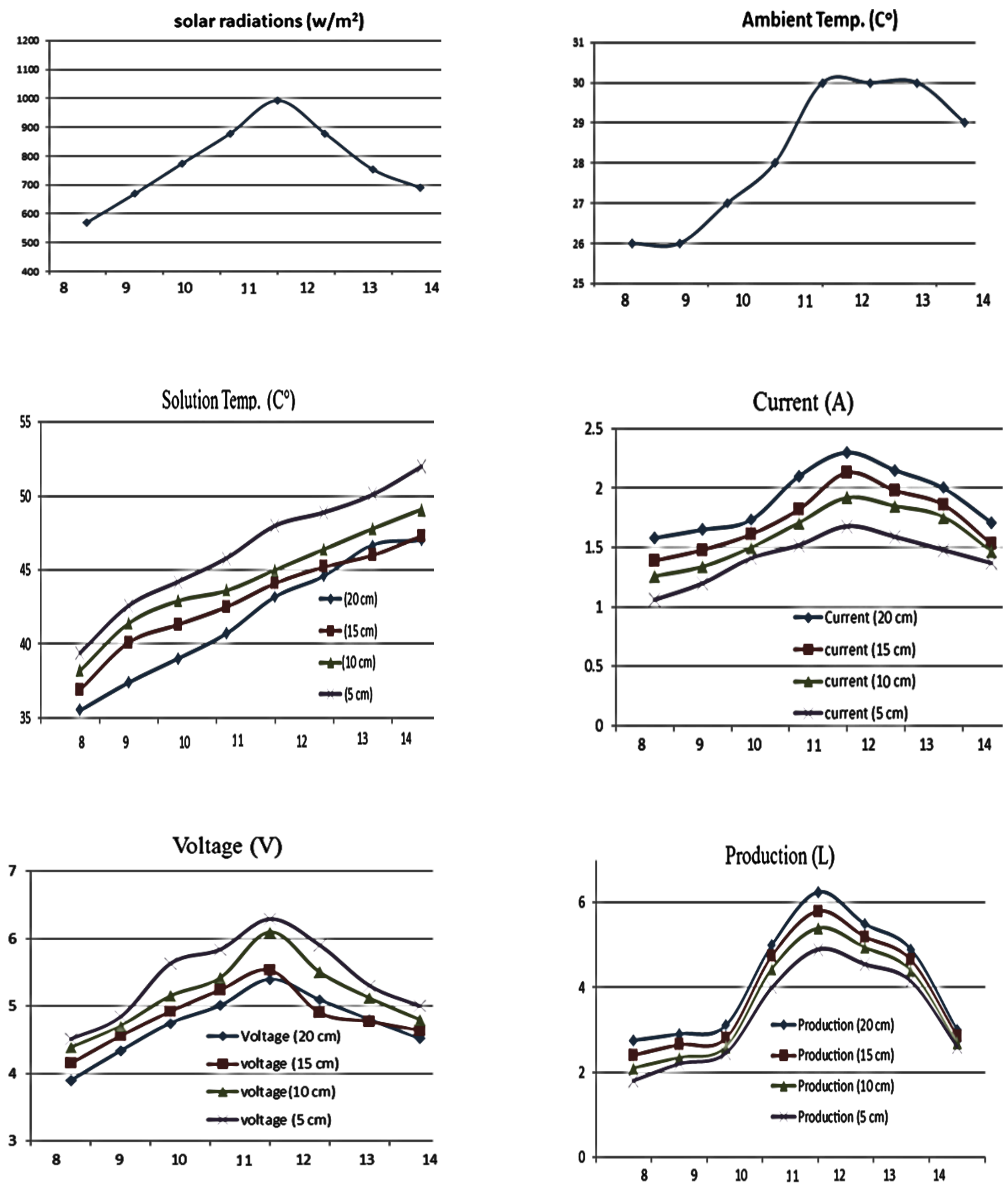

Figure 8: Part two effect of cylinder height on hydrogen and oxygen production

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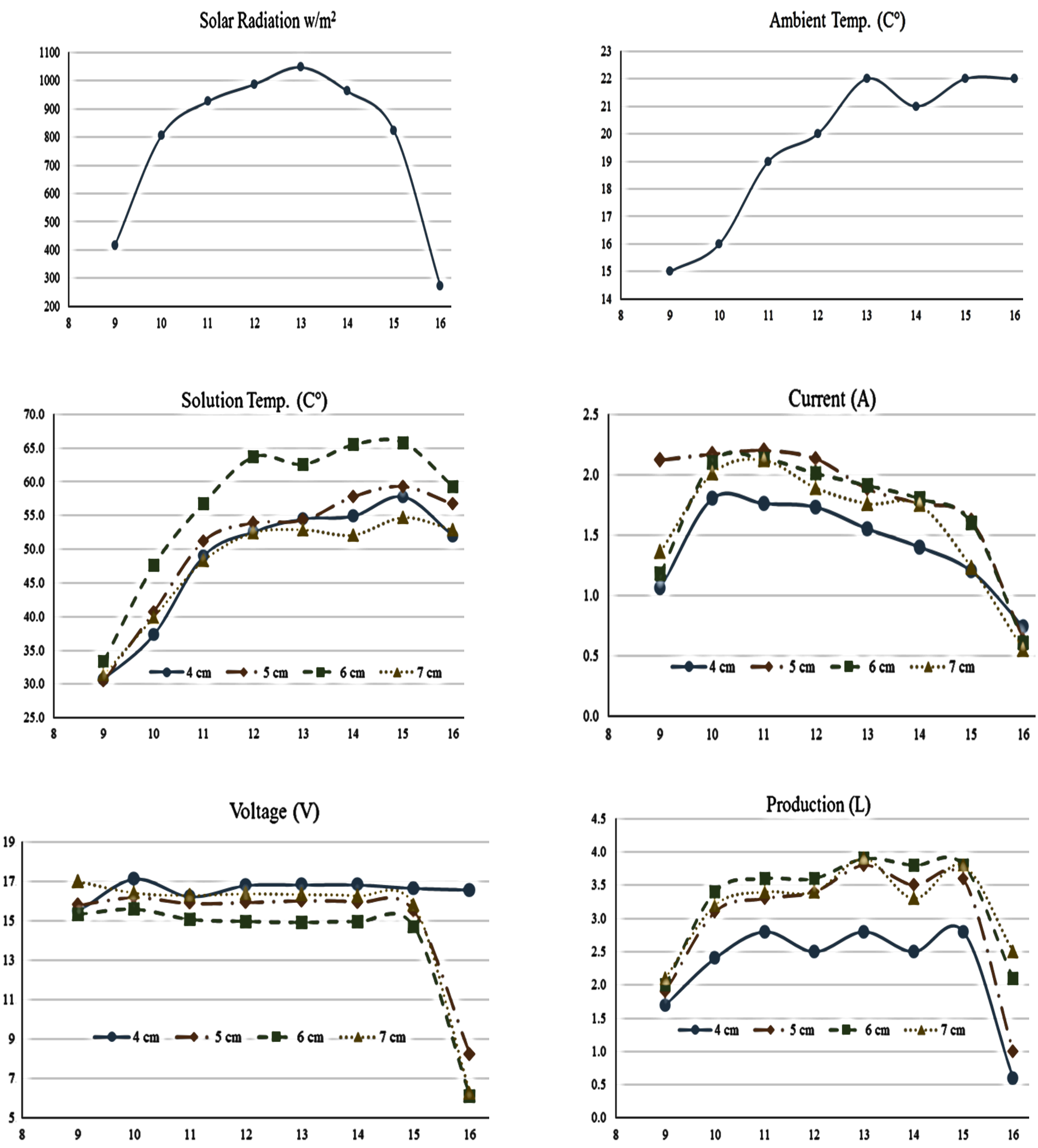

Figure 9: Part three effect of flat plate height on hydrogen and oxygen production

CONCLUSIONS

In this work, an experimental study was conducted to investigate the effect of electrodes' geometrical parameters on hydrogen and oxygen production. It is seen from the analysis of results that productivity increases as the gap between cylindrical electrodes decreases. In addition, as the height of the cylindrical electrodes increases the productivity increases. Moreover, the production increases with the increase in height in case of flat plate electrodes.

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