Technical University of Varna
Annual Journal
https://doi.org/10.29114/ajtuv.vol6.iss1.252
Vol. 6 Issue 1 (2022)
Published: 2022-07-30
ISSN 2603-316X (Online)

Experimental study on HHO electrolyzer efficiency – influence of the number of plates and their distance

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Abstract. *The present paper explores the factors influencing the efficiency of an HHO-gas-electrolyzer. The experiments were held in the respective laboratory at the Technical University of Varna with a principal focus on two of these factors –i.e., distance between the plates and the number of plates in a wet electrolyzer. The scientific tests were performed with all the remaining conditions being held constant and the appropriate results were obtained and visualized to disclose the most efficient electrolyzer setups.*

Keywords: hydroxy gas, oxyhydrogen gas, HHO gas, electrolyzer, MMW

1 Introduction

Hydrogen and hydrogen derivatives are widely used as feedstock, fuel, fuel additive, source of energy and energy storage option in the industry and transport. One of the main advantages of the hydrogen and the oxy-hydrogen, being one of the hydrogen derivatives, is the fact that no carbon emissions are produced in their usage.

Carbon emissions are one of the most important challenges, which the world has to address today, as they are one of the greatest polluters contributing to the greenhouse effect. This is the reason why all the national governments are heading towards carbon-neutral economies, which is supported by the global international organizations like the European Union with their Recovery Plan – NextGenerationEU – and different EU propositions and directives (**European Union, 2021**). The same direction can be seen in the drafts of Bulgarian Recovery Plan, where emphasis is placed on the low-carbon economy, green hydrogen and improvement of the hydrogen technologies and all of them will be supported by huge investments and initiatives.

The oxy-hydrogen gas (hydroxy gas, HHO gas, Brown's gas) is produced by electrolyzation of water and consists of 2 atoms of hydrogen and one atom of oxygen. Used as fuel additive, it improves the combustion, increasing, subsequently, the efficiency of the engine and reduces the harmful emissions. The usage of the HHO gas is highly dependent on its costs, which are defined by the efficiency of the HHO electrolyzers.

Many parameters have been studied in relation to improving the efficiency of the HHO electrolyzer. The most important from them are:

- Number of the electrodes (plates or rods) in the HHO electrolyzer (**Subramanian & Thangavel**, **2020**)
- The distance and the variation in the distance between the electrodes (**Al-Rousan & Musma, 2018**), (**Choodum et al., 2019**), (**Vasilev & Nedelchev, 2011**)
- Concentration of the electrolyte both KOH and NaOH (**Choodum et al., 2019**), (**Sudrajat et al., 2018**), (**Streblau et al.**, **2014**), (**Neukirchner et al., 2014**)
- Thickness of the electrolyzer plates (**Al-Rousan & Musma, 2018**)
- Temperature (**Choodum et al., 2019**)
- Electrical parameters (**Subramanian & Thangavel, 2020**)
- Electrolyte circulation (**Vasilev & Nedelchev, 2011**)

and many others

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The purpose of the current paper is to present our research into the strong influence of two factors on the HHO electrolyzer efficiency, namely:

- number of electrodes in the electrolyzer
- distance between the electrodes in the electrolyzer

2 Experiment set-up

2.1 Experiment configuration

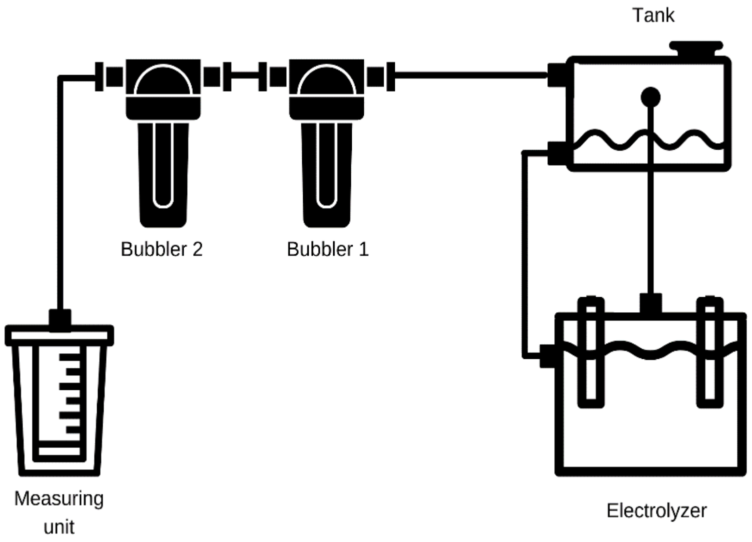

Fig. 1. Block diagram of the experiment.

The experiment was performed through the use of an HHO electrolyzer, to which DC power with given parameters was applied. The HHO cell is connected to a tank in a closed-loop, which supplies the KOH-water solution and receives the produced HHO gas. Due to its higher pressure, the accumulated HHO gas is pushed to the water filter 1 (bubbler 1), where the gas is purified. At the next steps, the gas enters the water filter 2 (bubbler 2) connected to the system in a reverse direction and filled with pure water. The gas, upon entering bubbler 2, is pushing the water out of the bubbler. The water spills over into the measuring unit and is used for measuring the volume of the produced gas. The position of the different equipment units is kept constant

2.2 HHO electrolyzer

The HHO electrolyzer, used in the research is a wet electrolyzer and has the following parameters:

Table 1. Electrolyzer parameters.

Outer dimensions	**Unit**	**Value**
Length	mm	240
Width	mm	240
Height	mm	240
Inner dimensions		
Length	mm	210
Width	mm	210
Height	mm	210
Volume	liter	9.26

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The electrodes for the electrolyzer are in the form of steel plates with the following specifications:

- Material stainless steel 316
- Thickness 1.5 mm
- Dimensions 190 x 190 mm

The metal plates are connected via plastic studs and nuts to avoid short-circuit. For the same reason, the distance between the plates is arranged with plastic washers of 1,6 and 2mm in series.

Potassium hydroxide (KOH) was used, for the purposes of the present experiment, as electrolyzer catalyst. As the HHO electrolyzer is the wet-type, less catalyst was envisaged when compared to the dry electrolyzers due to the lower resistivity of the whole system. Bigger ratio of the catalyst solution can lead to closing the current lines outside the electrode pack, thus lowering the efficiency of the HHO electrolyzer. The lower solution of the catalyst is one of the advantages of the wet-type electrolyzer too as, the bigger the catalyst concentration is, the more harmful to all the parts, gaskets and sealants etc. it is, thus increasing the production and operating costs of the system. The wet-type gas runs at a more stable production rate too (**Sudrajat et al., 2018**). Constant solution of 0.5-1% KOH was kept for the entire course of the experiment.

The HHO electrolyzer has one inlet (connection to the tank) on the upper side and 3 outlets on the top side for the HHO gas according to Fig.2

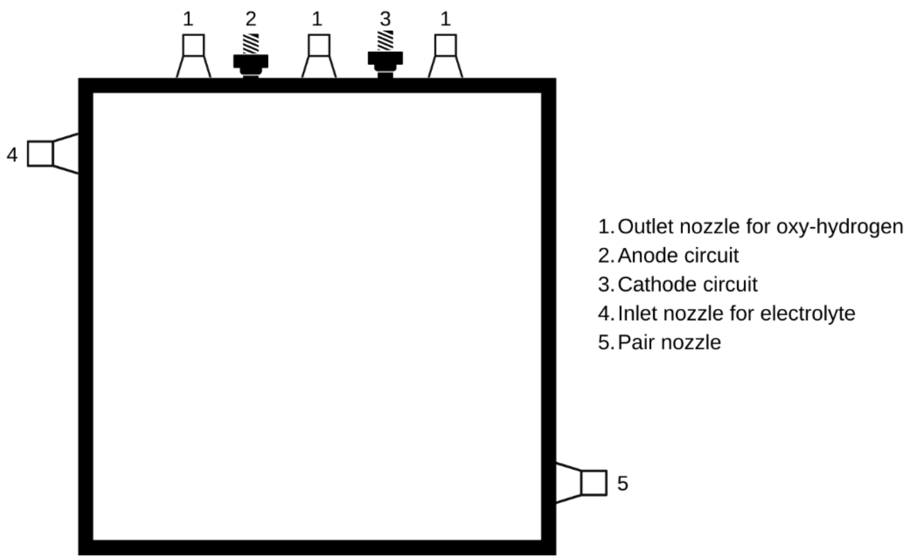

Fig. 2. HHO Electrolyzer outlook

2.3 Electrical equipment

The electrical equipment needed to provide the power for the HHO-gas production was connected according to the schematic representation in Fig. 3.

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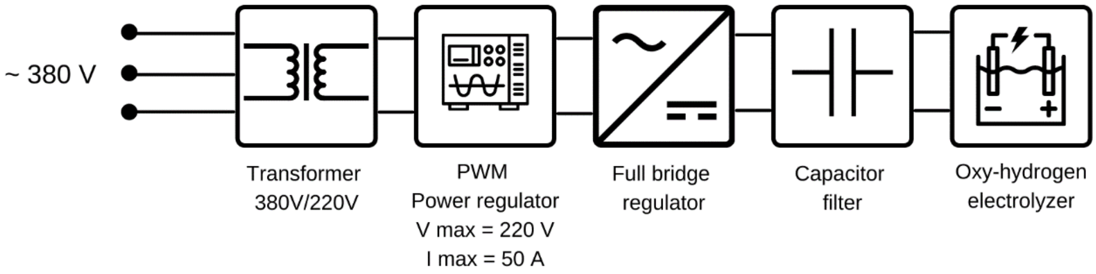

Fig. 3. Electrical equipment.

and consists of three phase transformer, pulse width modulation regulator, bridge rectifier, capacitors and oxy-hydrogen electrolyzer

2.4 Test procedure and measurements

The following protocols were used throughout the experiments:

- The test equipment and their parameters was not changed except for the internal set-up of the HHO electrolyzer in terms of the number of plates and distance between them
- The position of the equipment units and the connections between them was unaltered
- The DC voltage of the supplied power was kept constant for the tests. Therefore, the current level had to be changed so that the voltage level is maintained. The electrical parameters were controlled by multi-sets
- The production efficiency of the HHO electrolyzer is calculated by the length of time for which it produces 300ml HHO gas, i.e., the time for which the produced gas pushes out 300ml of water from bubbler 2.
- The measuring of these 300ml of water started only after the measuring unit has initially received the first 300ml of water. Compliance with this requirement, assures that any imbalances and disturbances in the HHO gas flow, due to initial start-up, empty volumes in the system and pressure deviations in the equipment are avoided
- At least 2 measurements per HHO electrolyzer set-up were made and their averages were taken
- The temperature during the tests was in the range of 46÷50°C
- The time was measured by a chronometer
- The tests were made in the presence of at least 2 of the researchers and the appropriate records were taken

The volume of the produced HHO gas is calculated in milters or in liters. The production rate of a HHO electrolyzer is calculated either in volume per time such as LPM (liter per minute), or milliliters per minute (**Choodum et al., 2019**), (**Subramanian & Thangavel**, **2020**), (**Sudrajat et al., 2018**).

The parameter volume per energy such as [ml/kJ] (**Enshasy et al., 2020a**) can be used for comparison.

Nevertheless, in order to calculate the total HHO electrolyzer efficiency more carefully and correctly, it is measured and reconciled by the parameter **MMW** (**Vasilev & Nedelchev**, 2011), (**Streblau et al., 2014**), (**Neukirchner et al., 2014**), (**Enshasy et al., 2020b**), which describes the volume of produced gas in milliliters per time in minutes and the power needed for the production in watts. Formula (1) describes the equation applied.

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$$MMW = \frac{V}{t.P} \quad (1)$$

where:

V, ml – the volume of the produced gas in milliliters
t, min – the time for production in minutes
P, W – the power needed for the production

3 Results

The laboratory tests of the HHO electrolyzer were made at the Technical University of Varna premises. The following results were reached.

3.1 Distance between the plates

The tests were made on 2 different set-ups of the HHO electrolyzer:

- 2-plate electrolyzer – in this set-up both plates are active – 1 cathode and 1 anode

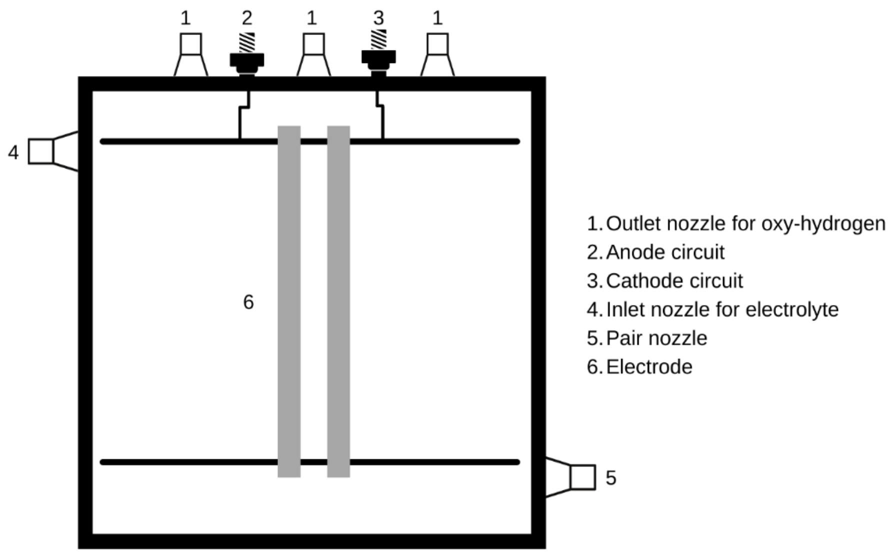

Fig. 4. 2-plate electrolyzer.

- 3-plate electrolyzer – in this set-up 2 active plates and 1 neutral are present – 1 cathode, 1 neutral and 1 anode

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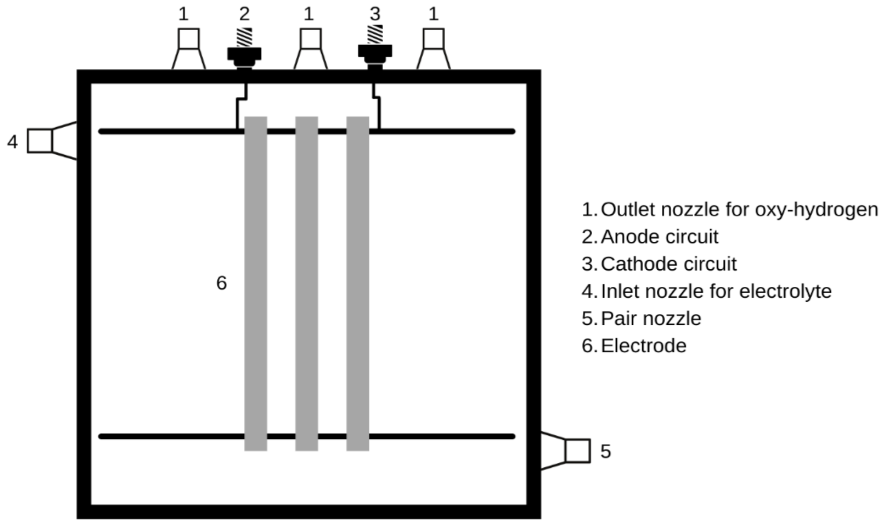

Fig. 5. 3-plate electrolyzer.

Studied, at first, was the influence of the distance between the electrodes (metal plates) on the efficiency of the wet electrolyzer. The distance was gradually increased from 1.6mm to 8 mm for the 2 electrode and the 3-electrode set-up

The results obtained from the tests are depicted in Figures 6-9 revealing the tendencies clearly.

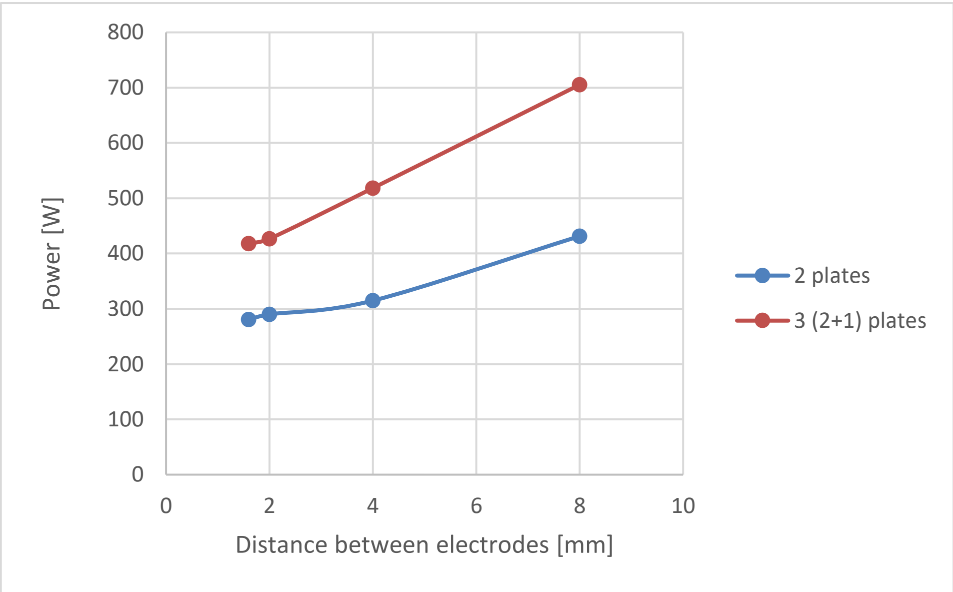

Fig. 6. Distance between the plates and the power needed

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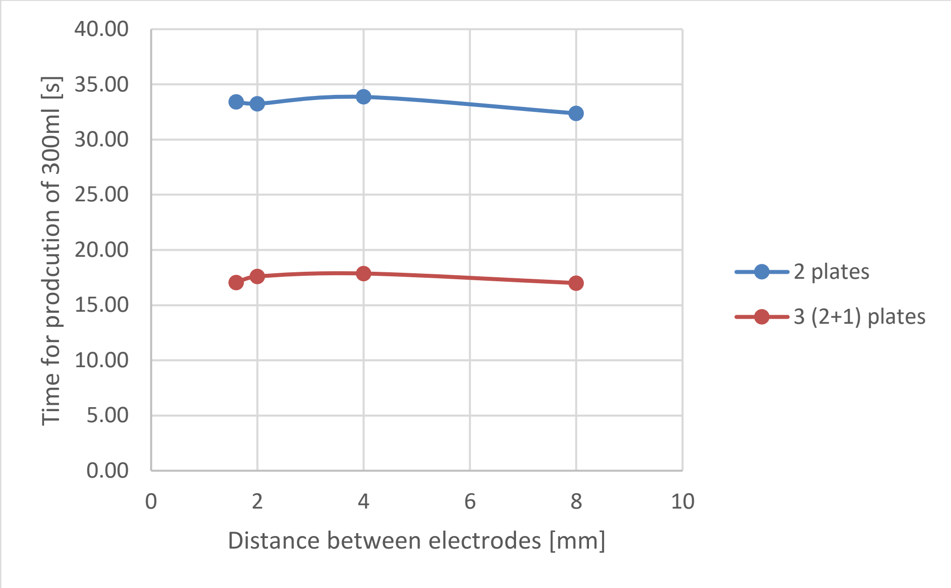

Fig. 7. Distance between the plates and time needed for producing 300ml of HHO gas

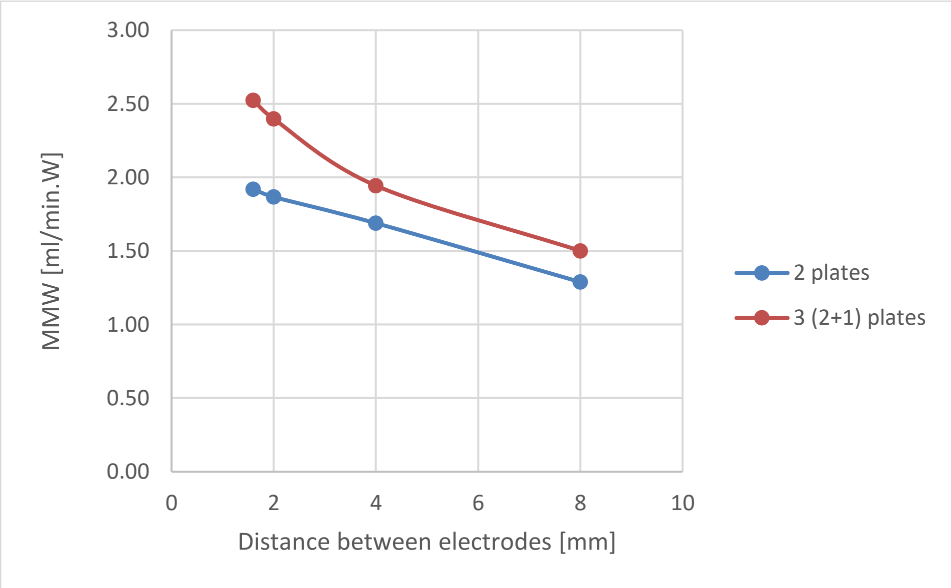

Fig. 8. Distance between the plates and efficiency of the HHO-electrolyzer

It is obvious from Fig.6 that the current, and thence, the power consumed, were increased in order to compensate for the lower conductivity of the electrolyzer, which is due to the bigger distance between the plates. The time for producing 300ml of gas in both set-ups is fairly constant showing a slight increase in the beginning (distances 1.6-4mm) and subsequent decline with about 4% - see Fig.7. However, the increase of the power needed is much higher than the decrease in time, resulting in a drop of the MMW from 1.92 to 1.29 or with 32.8% for the 2-plate set-up and from 2.52 to 1.50 or with 40.4% for the 3-plate set-up shown in Fig.8.

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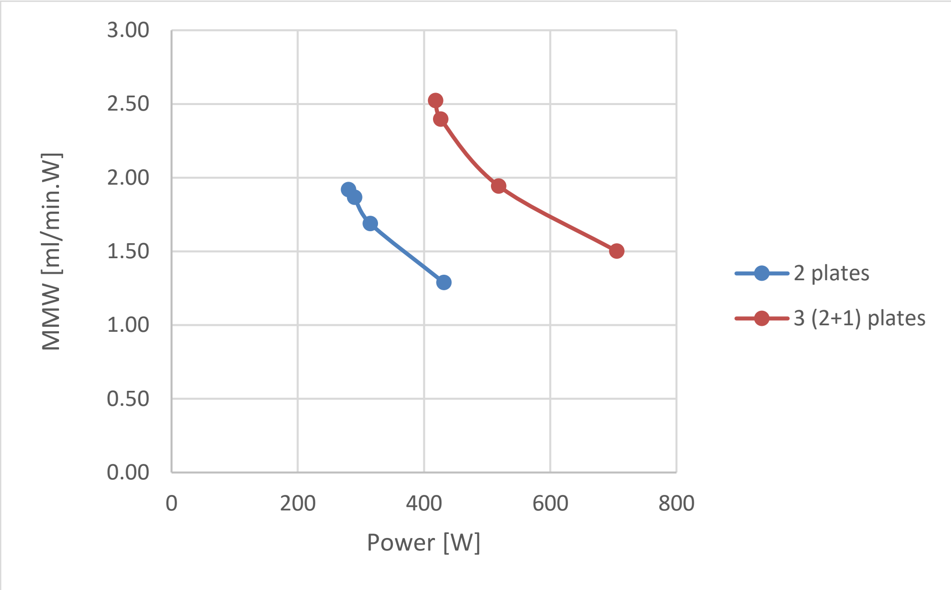

Fig. 9. Reference between efficiency of the HHO-electrolyzer and the power needed

The negative (inverse) relation between the efficiency and the power consumed by the electrolyzer is seen in Fig.9 and the almost straight lines show the negative effect of the increased power vs. the very small positive effect of the decreased production time.

The results from the first stage of our experiment clearly show that the efficiency of the HHO-electrolyzer is the highest when the distance between the plates is the smallest – 1.6mm. These research findings are, indeed, in line with the expectations, as increasing the distance between the electrodes increases the resistance of the electrical circle, and thus, more energy is needed to produce the same quantity of gas. The same results and conclusions are observed in (**Choodum et al., 2019**) for these temperature ranges. Other research studies show a slight increase in MMW rate after the minimum distance, due to the fact that at the minimum distance the gas bubbles do not have enough space to move, which explains the need for additional circulation (**Vasilev & Nedelchev**, **2011**).

After reaching the most efficient set-up of the HHO-electrolyzer in terms of the distance between the plates – 1.6mm - further tests into the influence of the number of plates on the HHO-electrolyzer efficiency were made with the same design.

3.2 Number of plates

While keeping the voltage constant, the number of the plates was gradually increased from 2 to 11 pcs, and only the 2 end plates were basically kept active – so, there is always only 1 cathode and 1 anode available. The distance between the plates is always 1.6mm, being the most effective one (please see (point 3.1). The results of the tests are provided in Figures 10÷13.

It can be seen from Figure 11, that the time for the production of the same amount of gas decreases with the addition of every new plate (electrode), which is a result of the increased plate area for the gas production. It is also noticeable from Fig.12 that with this solution of KOH, the MMW reaches its maximum at 11 electrodes. Furthermore, it is obvious from the graphs that after the first neutral plate being installed, the MMW ratio is almost equal in the 2.43-2.57 range. So, the efficiency of the HHO electrolyzer stays fairly constant, which is supported by the graph in Fig.10 showing that the power needed for the production increases linearly with every additional neutral plate. Fig.13, which shows that the reference between the power needed and the efficiency of the electrolyzers has the same pattern as the graph in Fig.12, also confirms the preceding observation. The same is additionally advised in (**Subramanian & Thangavel**, **2020**). That leads to the conclusion that the number of the plates does not have a strong

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influence on the efficiency of the Electrolyzer, as long as enough power (current) is provided for the production.

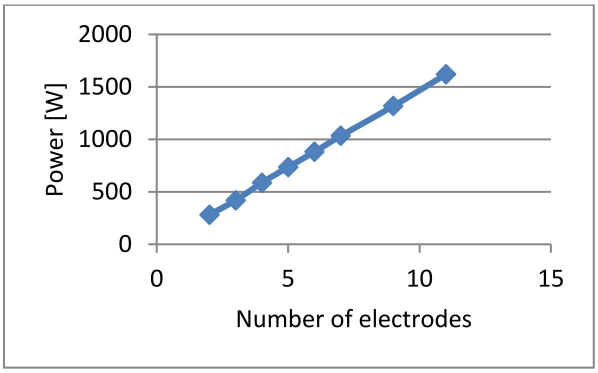

Fig. 10. Number of electrodes and consumed power

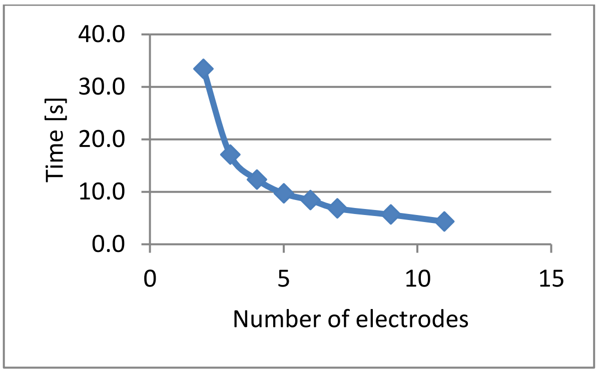

Fig. 11. Number of electrodes and time for producing 300ml of HHO gas

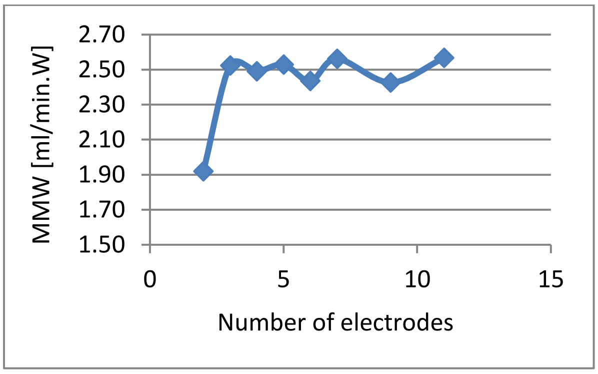

Fig. 12. Number of electrodes and Efficiency of the HHO electrolyzer

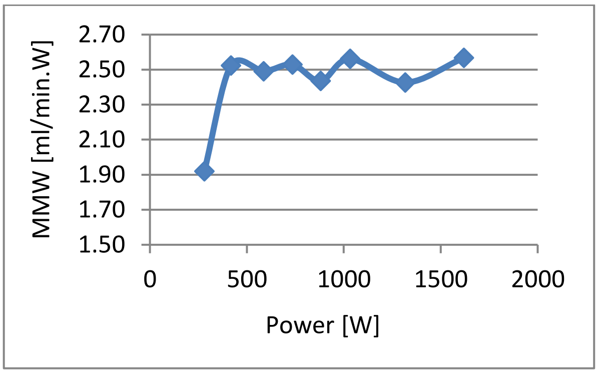

Fig. 13. Reference between efficiency of the HHO-electrolyzer and the power needed

4 Conclusions

The efficiency of the HHO-electrolyzer is dependent on a lot of factors and 2 of them – distance between the electrodes and their number – were studied in this research. The HHO-electrolyzer efficiency is found to benefit from the smaller distance between the metal plates, reaching its maximum at the smallest distance of 1.6mm. The increase in the number of electrodes, does not have a profound influence on the efficiency, as long as the electrolyzer is supplied with enough power to keep the voltage level constant. Nevertheless, the number of the plates is in direct connection with the produced quantity of gas – in order to increase it, the number of the plates should also be increased.

Acknowledgments

This paper is developed in the frames of project „Investigation and analysis of the efficiency of electrolyze device operation in hydroxy generation" - NP2/2021, at Technical University of Varna.

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References

Al-Rousan, A. & Musma, S. (2018). Effect of anodes-cathodes inter-distances of HHO fuel cell on gasoline engine performance operating by a blend of HHO. *International Journal of Hydrogen Energy, 43(*41), 19213-19221. https://doi.org/10.1016/j.ijhydene.2018.08.118

Choodum, N., Sangwichien, C. & Yamsaengsung, R. (2019). Optimization of a Closed-Loop HHO Production System for Vehicles and Houses. *Environmental Progress & Sustainable Energy*, *38*(1), 268 - 277. https://doi.org/10.1002/ep.12909

Enshasy, H, Al-Haija, Q., Al-Amri, H., Al-Nashri, M., Al-Muhaisen, S. & Al-Tarayrah, M. (2020a). A Comprehensive Construction of Hydrogen-Hydrogen-Oxygen (HHO) Cell as Renewable Energy Storage. *WSEAS TRANSACTIONS ON SYSTEMS, 19*, 121-132. https://doi.org/10.37394/23202.2020.19.17

Enshasy, H, Al-Haija, Q., Al-Amri, H., Al-Nashri, M., Al-Muhaisen, S. & Al-Tarayrah, M. (2020b). Elaborated Mathematical Model for Hydrogen-Hydrogen-Oxygen Energy Storage Cell. *WSEAS TRANSACTIONS ON CIRCUITS AND SYSTEMS. 19*, 116-128. https://doi.org/10.37394/23201.2020.19.14

European Union. (2021). *Proposal for DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL (2021) amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652.*

Neukirchner, L., Görbe, P., Magyar, A. & Attila, G. (2014). Measurement-based modelling and simulation of a hydrogen generating dry cell for complex domestic renewable energy systems. *Hungarian Journal of Industry and Chemistry*, *42*(2), 85–89. https://www.researchgate.net/publication/280729095

Streblau, M., Aprahamian, B., Simov, M, Dimova, T. (2014). The influence of the electrolyte parameters on the efficiency of the oxyhydrogen (HHO) generator. *18th International Symposium on Electrical Apparatus and Technologies (SIELA)*, (pp. 1-4). IEEE. https://doi.org/10.1109/siela.2014.6871898

Subramanian, B. & Thangavel, V. (2020). Analysis of onsite HHO gas generation system. *International Journal of Hydrogen Energy*, *45*(28), 14218-14231. https://doi.org/10.1016/j.ijhydene.2020.03.159

Sudrajat ,A., Handayani, E., Tamaldin, N. & Yamin, A. (2018). Principle of generator HHO hybrid multistack type production technologies to increase HHO gas volume. In *SHS Web of Conferences*, *49*, p.02016. EDP Sciences. https://doi.org/10.1051/shsconf/20184902016

Vasilev, R. & Nedelchev, I. (2011). Electrolytic cells for oxyhydrogen productions. Effects of circulation of the electrolyte and the electrode gap on the effectiveness. *Annual of the Technical University of Varna*, *1*, pp. 91-95. https://www1.tu-varna.bg/tu-varna/images/izdatelska_deinost/god/godishnik_2011/Godishnik_TU_2011_tom_I.pdf