International Journal of
Innovation in Mechanical Engineering & Advanced Materials (IJIMEAM)
https://publikasi.mercubuana.ac.id/index.php/ijimeam

Vol.3 (No.2). 2021. pp. 44-49
Published online: Sept. 4, 2021
ISSN: 2477-541X

FLOW FIELD PLATE DESIGN ANALYSIS WITH CROSS-SECTION WAVE RECTANGULAR SERPENTINE USING 3D FLOW SIMULATION ON PROTON EXCHANGE MEMBRANE FUEL CELL

T. I. Prasetya[1], D. S. Khaerudini[2]*

[1]Department of Mechanical Engineering, Universitas Mercu Buana, South Meruya No. 1, Jakarta, 11650, Indonesia
[2]Research Center for Physics, Indonesian Institute of Sciences (LIPI), Gd.440 Kawasan Puspiptek Serpong, Tangerang Selatan, Banten, 15314, INDONESIA

Abstract
The availability of petroleum which continues to decrease and the level of public consumption which is always increasing are serious problems today. Renewable energy needs to be researched on an ongoing basis to anticipate the availability problems above. Proton Exchange Membrane Fuel Cell (PEMFC) is an environmentally friendly source of electrical energy because it only requires hydrogen and oxygen as raw materials and water as a result of the reaction. This study will discuss the PEMFC flow field plate because this component dominates the weight and cost of manufacture. Research on flow field plate PEMFC with wave rectangular cross-section is necessary to develop the PEMFC concept with better performance results. This study aims to determine the effect of the wavy cross-section shape on the distribution of channel average speed, channel outlet speed, inlet pressure, channel average pressure, and channel outlet pressure. This study uses a computational fluid dynamic (CFD) method using SolidWorks flow simulation software. This study provides an overview of the serpentine type of flow field plate with a wave rectangular and rectangular cross-section. The wave rectangular cross-section has a higher average velocity, outlet velocity, inlet pressure, and pressure than the rectangular cross-section. This is what will make PEMFC performance higher The wave rectangular cross-section has nearly the same number of outlet pressures as the rectangular cross-section. Possible development of this research is the creation of simulation software to calculate other parameters that affect PEMFC performance.

Keywords: Cross-section, PEMFC, Flow field, Serpentine

*Corresponding author: Tel. +62 85711461440
E-mail address: deni.shidqi.khaerudini@lipi.go.id

1. Introduction

Generating energy with raw materials that are safe for the environment can be a solution to current environmental problems. The environment needs to be maintained to have a clean, safe and comfortable life. An environment with a good ecosystem will form a balance to ensure sustainable life. The source of fuel oil continues to decrease and its usage is increasing. The increasing use encourages this research to generate new research in the field of renewable alternative energy that is environmentally friendly.

Proton Exchange Membrane Fuel Cell (PEMFC) has a power output > 250 kW, can work at low temperatures at 30–100°C, produces no environmental pollutants, and a source of hydrogen can be stored in high numbers and densities. H2 on the anode side and oxygen on the cathode side as reactants. H_2 is converted to 2H+ with a platinum catalyst on the anode side. O_2 is converted to ½O_2 with a platinum catalyst on the cathode side. The reactions of the two reactants above produce electricity, heat, and water [1].

This energy source has high efficiency and is clean in nature. This is what makes PEMFC the most promising alternative energy to use for the future [2]. But the use of PEMFC on a large scale is also expensive. Bipolar plates are an important part of PEMFC, distributing oxides, reductants, channeling electric current between single cells, removing unused heat from the reactive area, preventing gas leakage, and conducting cooling. Currently, the bipolar plate price reaches 15-30% of the total cost of making PEMFC [3], [4].

Based on the classification of bipolar plate materials, materials that are usually used include graphite, metal, and composites [5]. Graphite bipolar plates have good electrical conductivity, thermal conductivity, and corrosion resistance. Processing costs and expensive materials are constraints for graphite bipolar plates [6]. Graphite bipolar plates

Vol.3 (No.2). 2021. pp. 44-49
Published online: Sept. 4, 2021
ISSN: 2477-541X

have a higher gas permeability. Metal bipolar plates have higher mechanical strength, lower gas permeability, low processing costs, but have problems in rust resistance in moist and acidic PEMFC conditions [7]–[9].

Flow field design is one of the factors that influence PEMFC performance. The cross-sectional geometry and flow field pattern will affect gas transportation, water management, and fuel efficiency. The goal of the flow field design optimization is to increase the transport of reactants to the porous gas diffusion layer and the catalytic layer to participate in electrochemical reactions that are closely related to water transport within cells [10]. The most common flow field patterns are parallel, pin, serpentine, interdigitated, spiral, radial, bio-inspired, tubular, cascade patterns. All flow field patterns are compared against their performance. Several studies using analytical, experimental, and numerical methods say that the serpentine type has the best performance among all patterns [11].

The serpentine groove pattern has a higher power density than other types. The reactant gas will be made to flow across the entire active area. This condition results in a large pressure loss along the channel. The serpentine groove pattern with more than one channel will anticipate accumulation [1]. The parallel type has the disadvantage of causing water droplets and the serpentine groove pattern with four channels can improve cell performance and anticipate the occurrence of water droplets [12].

The channel width and height have an impact on the yield of PEMFC power. The discharge of water increases as the height of the canal decreases, but the performance of the channel also decreases. PEMFC performance drops in proportion to the increase in channel width because low gas velocity results in less water discharge. This case shows higher cell performance in a smaller channel cross-sectional area, due to the impact of higher gas velocity [10]. Cell performance does not have a significant effect on channel depth [13].

The power generated by PEMFC is influenced by temperature, pressure, humidity, gas composition, and reactant utilization. Excessive pressure drop can make FFP more prone to clogging due to the formation of water droplets in the channel [1]. Hydrogen that enters the channel will experience a decrease in pressure. The pressure drop will have an impact on the resulting current [14]. The flow rate of the reactants must be distributed evenly across the entire active area of the FFP [1].

Seyhan et al. [15] conducted a study using a sinusoidal serpentine flow field. The research variables consist of flow rate, amplitude, and temperature. The method used is an artificial neural network. The result is PEMFC with the lowest amplitude can improve performance up to 20.15% compared to conventional serpentine channel. X. Chen et al. [16] investigated on a novel 3D wave flow channel using the CFD method on the cathode side. The results show that the wave flow channel is better at improving PEMFC performance up to 23.8% than the conventional type.

This study aims to determine the effect of the cathode side wave rectangular cross-section shape on the distribution of channel average velocity, channel outlet speed, inlet pressure, channel average pressure, and channel outlet pressure.

2. Experimental and Procedures

2.1 Materials

Data were collected by measuring the flow field plate (FFP) measurement reference with a rectangular cross-section. The data are as presented in Table 1 as follows.

Table 1. Specification data flow field plate with a rectangular cross-section [17].

No.	Description	Value
1	Pattern	Serpentine
2	Active area	50 mm x 50 mm
3	Number of channels	6
4	Canal width	1 mm
5	Cross section	Rectangular
6	Canal depth	1
7	Number of inlets	2
8	Inlet diameter	1.5 mm
9	Number of outlets	4
10	Outlet diameter	1.5 mm
11	Material	Graphite

The next process is the design of a three-dimensional FFP model. The three-dimensional model will be used for the simulation process. The simulation process carried out on rectangular FFP aims to determine the pattern of velocity and pressure distribution, as illustrated in Fig. 1.

Vol.3 (No.2). 2021. pp. 44-49
Published online: Sept. 4, 2021
ISSN: 2477-541X

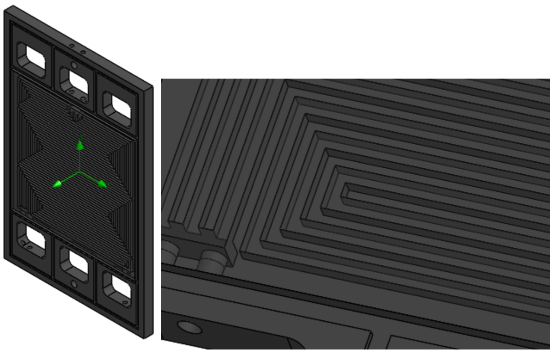


Fig. 1. Design flow field plate with a rectangular cross-section

The FFP design with a rectangular cross-section is developed in the form of a wave rectangular cross-section. The distinguishing factor of this study is the channel depth of 1 mm for the maximum height and 0.45 mm for the minimum height, as detailed in Table 2.

Table 2. Specification data flow field plate with a wave rectangular cross-section.

No.	Description	Value
1	Pattern	Serpentine
2	Active area	50 mm x 50 mm
3	Number of channels	6
4	Canal width	1 mm
5	Cross section	Wave Rectangular
6	Canal depth	1 mm (max) and 0.45 mm (min)
7	Number of inlets	2
8	Inlet diameter	1.5 mm
9	Number of outlets	4
10	Outlet diameter	1.5 mm
11	Material	Graphite

The next process is making a wave rectangular cross-section design. Fig. 2 shows the design of a rectangular wave cross-section that will be used for the simulation and analysis process.

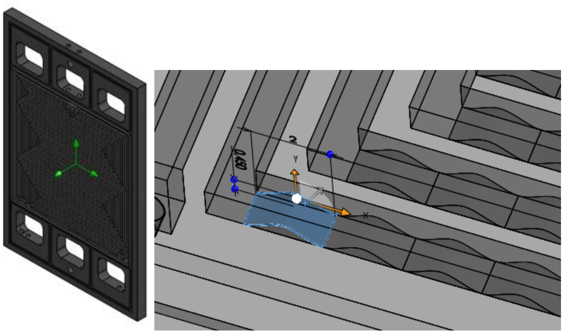


Fig. 2. Design flow field plate with a wave rectangular cross-section.

2.2 Experiment

The experimental process begins with the process of data collection and design process. The data collection process was carried out on a flow field plate with a common rectangular cross-section. The design process uses the 3D modeling feature in SolidWorks software. The resulting design is a flow filed plate design with a common rectangular cross-section and a wave rectangular cross-section.

The simulation process starts with creating a lid. creating lid is determining the geometric boundary in the inlet and outlet area. The next process is meshing, which is the process of breaking the 3D design into smaller objects so that they can become measurement objects. After the meshing process is carried out the flow simulation project setup process includes naming the project, selecting the unit of measurement, selecting the type of analysis for internal or external analysis, selecting the type of fluid and flow type, selecting the condition of the walls. After the setup process, the boundary condition process is carried out to provide inlet and outlet parameters. Then the goal-setting process is carried out to determine the average speed, outlet speed, inlet pressure, average pressure, outlet pressure, and pressure loss. Then finally run the simulation process and export all the result data.

The cross-section with rectangular and wave rectangular is carried out by simulation process. The simulation process uses boundary parameters, as shown in Table 3 as follows.

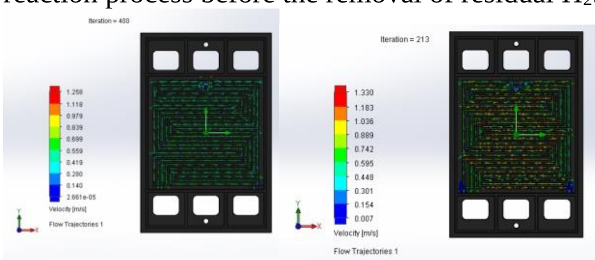
Table 3. Simulation boundary parameters

Parameter	Value
Volume velocity (cm^3/s)	1 –5
Pressure (Pa)	101325
Temperature (K)	323

3. Results and Discussion

3.1 Result of Main Experiment

The velocity simulation results show a map of the velocity distribution across the channel area, as in Figure 3. The red color on the wave rectangular cross section indicates that the average velocity of the flow is higher and more even. Decreasing the outlet area velocity in the serpentine rectangular wave will hold back the rate of reactant removal, maximizing the reaction process before the removal of residual H_2.



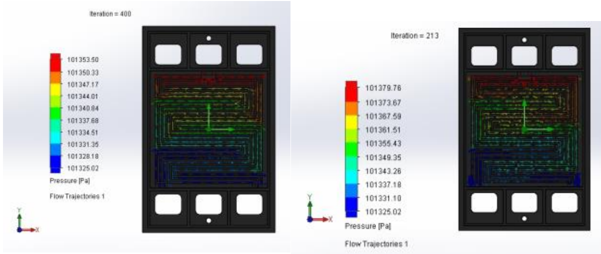
(a) Rectangular (b) Wave Rectangular

Fig. 3. Flow velocity distribution pattern at a discharge of 3 cm^3/s.

International Journal of
Innovation in Mechanical Engineering & Advanced Materials (IJIMEAM)
https://publikasi.mercubuana.ac.id/index.php/ijimeam

Vol.3 (No.2). 2021. pp. 44-49
Published online: Sept. 4, 2021
ISSN: 2477-541X

The simulation results of the flow pressure show a map of the pressure distribution in the entire channel area, as in Fig. 4. The pressure distribution map in the two types of the cross-section shows almost the same color or result. But the wave rectangular serpentine type has a higher working pressure than the rectangular type.



(a) Rectangular (b) Wave Rectangular

Fig. 4. Flow pressure distribution pattern at a discharge of 3 cm³/s.

3.2 Result of Secondary Experiment

The results of this study are in the form of data on average speed, outlet speed, inlet pressure, average pressure, outlet pressure, and pressure drop. Data differences can be seen in Table 4 below.

Table 4. The results of data processing simulation of velocity distribution and pressure distribution

Description	Cross Section	Inlet Debit (cm³/s)				
		1	2	3	4	5
Average velocity	*Rectangular* (m/s)	0.171	0.342	0.514	0.686	0.858
	Wave Rectangular (m/s)	0.207	0.414	0.621	0.828	1.035
Outlet velocity	*Rectangular* (m/s)	0.164	0.332	0.503	0.677	0.855
	Wave Rectangular (m/s)	0.162	0.326	0.495	0.668	0.844
Inlet pressure	*Rectangular* (Pa)	101334.833	101344.705	101354.610	101364.551	101374.530
	Wave Rectangular (Pa)	101343.424	101362.093	101380.965	101400.043	101419.321
Average pressure	*Rectangular* (Pa)	101329.918	101334.854	101339.804	101344.770	101349.753
	Wave Rectangular (Pa)	101334.306	101343.729	101353.254	101362.876	101372.594
Outlet pressure	*Rectangular* (Pa)	101325.001	101325.005	101325.011	101325.021	101325.033
	Wave Rectangular (Pa)	101325.001	101325.005	101325.011	101325.020	101325.032
Pressure drop	*Rectangular* (Pa)	9.832	19.700	29.598	39.530	49.497
	Wave Rectangular (Pa)	18.423	37.088	55.954	75.023	94.289

The results of the average channel velocity show that the wave rectangular cross-section type has a higher average channel velocity than the rectangular cross-section type. The comparison of the results of the average channel speed is shown in Fig. 5 below.

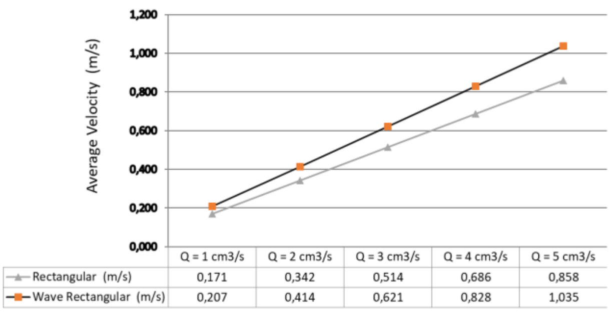


Fig. 5. Graph of average velocity against inlet debit on the serpentine flow field plate

The results of the channel velocity have shown that the wave rectangular cross-section has an average channel velocity that is almost the same as the rectangular cross-section. The comparison of the channel speed results is shown in Fig. 6 below.

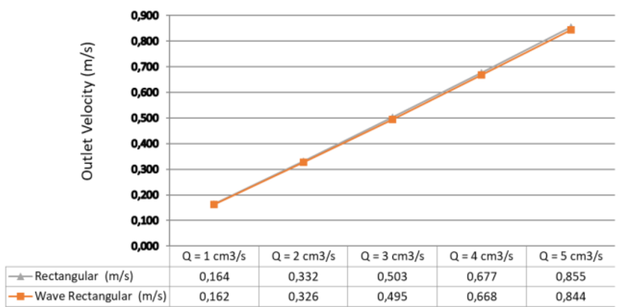


Fig. 6. Graph of outlet velocity against inlet debit on the serpentine flow field plate

The results of the channel inlet pressure show that the wave rectangular cross-section type has a higher inlet pressure than the rectangular cross-section. The comparison of the results of inlet pressure is shown in Fig. 7.

Vol.3 (No.2). 2021. pp. 44-49
Published online: Sept. 4, 2021
ISSN: 2477-541X

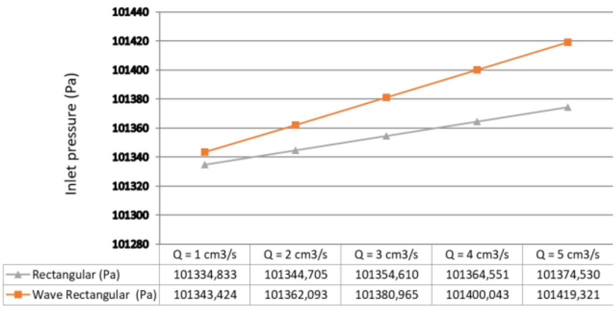


Fig. 7. Graph of inlet pressure against inlet debit on the serpentine flow field plate

The results of the mean channel pressure show that the wave rectangular cross-section type has a higher average pressure than the rectangular cross-section. The comparison of the results of the inlet pressure is shown in Fig. 8.

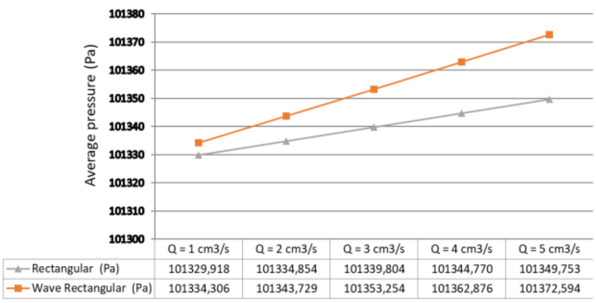


Fig. 8. Graph of average pressure against inlet debit on the serpentine flow field plate

The outlet pressure results show that the wave rectangular cross-section type has lower outlet pressure than the rectangular cross-section type. The comparison of the results of the outlet pressure is shown in Fig. 9.

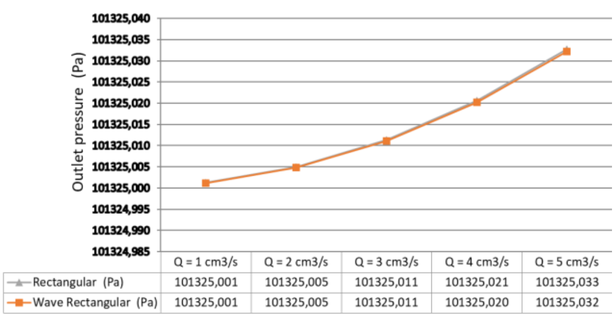


Fig. 9. Graph of average pressure against inlet debit on the serpentine flow field plate

The result of the loss of pressure shows that the wave rectangular type has a higher pressure lost than the rectangular type. Comparison of the resulting loss of pressure is shown in Fig. 10.

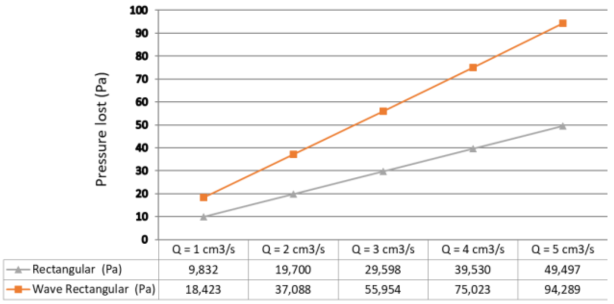


Fig. 10. Graph of inlet pressure against inlet debit on the serpentine flow field plate

4. Conclusions

The results of the research above have been simulated, analyzed, and processed data. The results of data processing can be drawn as follows. The higher average velocity of the rectangular wave rectangular cross-section will make PEMFC performance higher because the smaller cross- section makes the gas velocity higher and more evenly. The outlet velocity of the wave rectangular cross-section has almost the same value compared to the rectangular cross-section. It can indicate the depth which does not significantly affect the outlet speed of the duct. The inlet pressure, average pressure, and outlet pressure of the wave rectangular cross-section are higher than the rectangular cross-section. because the wave rectangular cross- section type has a smaller work volume than the rectangular cross-section type. The outlet pressure of the wave rectangular cross-section and rectangular cross-section has almost the same results because the area is close to the free area with a pressure of 1 atm.

5. Acknowledgements

Thanks are given to Department of Mechanical Engineering, Universitas Mercu Buana and Research Center for Physics, Indonesian Institute of Sciences (LIPI) for facilitating this research activity.

References

[1] S. Praneeth, A. Das, and F. Liou, "Design of metallic bipolar plates for PEM fuel cells.," Missouri University of Science and Technology. Center for Transportation, 2012.

[2] F. Xie *et al.*, "Recent progresses in H2-PEMFC at DICP," *J. Energy Chem.*, vol. 36, pp. 129–140, 2019, doi: 10.1016/j.jechem.2019.07.012.

[3] J. M. Andújar and F. Segura, "Fuel cells: History and updating. A walk along two centuries," *Renew. Sustain. energy Rev.*, vol. 13, no. 9, pp. 2309–2322, 2009.

[4] M. L. Perry and T. F. Fuller, "A historical perspective of fuel cell technology in the 20th

Vol.3 (No.2). 2021. pp. 44-49
Published online: Sept. 4, 2021
ISSN: 2477-541X

century," *J. Electrochem. Soc.*, vol. 149, no. 7, p. S59, 2002, doi: 10.1149/1.1488651.

[5] R. Taherian, "A review of composite and metallic bipolar plates in proton exchange membrane fuel cell: Materials, fabrication, and material selection," *J. Power Sources*, vol. 265, pp. 370–390, 2014.

[6] K. Yao, D. Adams, A. Hao, J. P. Zheng, Z. Liang, and N. Nguyen, "Highly conductive and strong graphite-phenolic resin composite for bipolar plate applications," *Energy & Fuels*, vol. 31, no. 12, pp. 14320–14331, 2017.

[7] V. Mehta and J. S. Cooper, "Review and analysis of PEM fuel cell design and manufacturing," *J. Power Sources*, vol. 114, no. 1, pp. 32–53, 2003.

[8] C. T. Wang *et al.*, "A modified serpentine flow slab for in Proton Exchange Membrane Fuel Cells (PEMFCs)," *Energy Procedia*, vol. 142, pp. 667–673, 2017, doi: 10.1016/j.egypro.2017.12.110.

[9] B. Wu, G. Lin, Y. Fu, M. Hou, and B. Yi, "Chromium-containing carbon film on stainless steel as bipolar plates for proton exchange membrane fuel cells," *Int. J. Hydrogen Energy*, vol. 35, no. 24, pp. 13255–13261, 2010.

[10] H.-C. Chiu, J.-H. Jang, W.-M. Yan, H.-Y. Li, and C.-C. Liao, "A three-dimensional modeling of transport phenomena of proton exchange membrane fuel cells with various flow fields," *Appl. Energy*, vol. 96, pp. 359–370, 2012.

[11] M. Z. Chowdhury and Y. E. Akansu, "Novel convergent-divergent serpentine flow fields effect on PEM fuel cell performance," *Int. J. Hydrogen Energy*, vol. 42, no. 40, pp. 25686–25694, 2017, doi: 10.1016/j.ijhydene.2017.04.079.

[12] E. L. Dewi and J. Raharjo, "Perbandingan Grafit Bipolar Plate Model Parallel dan Serpentine sebagai Komponen Separator pada Pemfc," in *Prosiding Seminar Nasional Teknoin*, 2008, vol. 3, no. November, pp. 47–50.

[13] Y. M. Ferng and A. Su, "A three-dimensional full-cell CFD model used to investigate the effects of different flow channel designs on PEMFC performance," *Int. J. Hydrogen Energy*, vol. 32, no. 17, pp. 4466–4476, 2007, doi: 10.1016/j.ijhydene.2007.05.012.

[14] J. Larminie, A. Dicks, and M. S. McDonald, *Fuel cell systems explained*, vol. 2. J. Wiley Chichester, UK, 2003.

[15] M. Seyhan, Y. E. Akansu, M. Murat, Y. Korkmaz, and S. O. Akansu, "Performance prediction of PEM fuel cell with wavy serpentine flow channel by using artificial neural network," *Int. J. Hydrogen Energy*, vol. 42, no. 40, pp. 25619–25629, 2017, doi: 10.1016/j.ijhydene.2017.04.001.

[16] X. Chen *et al.*, "Performance investigation on a novel 3D wave flow channel design for PEMFC," *Int. J. Hydrogen Energy*, no. xxxx, 2020, doi: 10.1016/j.ijhydene.2020.06.057.

[17] Teguh, "Bipolar Plate t5," vol. 1, no. Jakarta: Idea Laboratory Engineering, p. 1, 2018, [Online]. Available: https://drive.google.com/file/d/1jo7vZ0bpKj7mb4VDPlyPXtMdandWq5mG/view?usp=sharing .