CHAPTER 4

METHODOLOGY

The purpose of this chapter is to provide a brief description of the procedures of the numerical simulations and the experiments which were used to perform in the present study. The first section gives the details of the numerical simulations procedures that include; design flow field and results are shown velocity, pressure and electro chemical reaction in fuel cell. The experimental methods; there are a build the prototype of flow fields, test cell and measurement of current density and cell voltage.

4.1 Numerical Methods

In building mathematics model have 3 main steps, which component is 1. Pre-Processing 2. Processing and 3. Post-Processing

This step was building 3-D PEMFC modeling. The first, it builds gas flow channel was designed and polar plate. The design gas flow channels have many parameters for studied and based on parallel-serpentine flow field. In addition to that building diffusion layer modeling, catalyst layer modeling and membrane layer modeling have 0.26 mm., 0.028 mm. and 0.23 mm., respectively. The PEMFC model is shown in 4.1

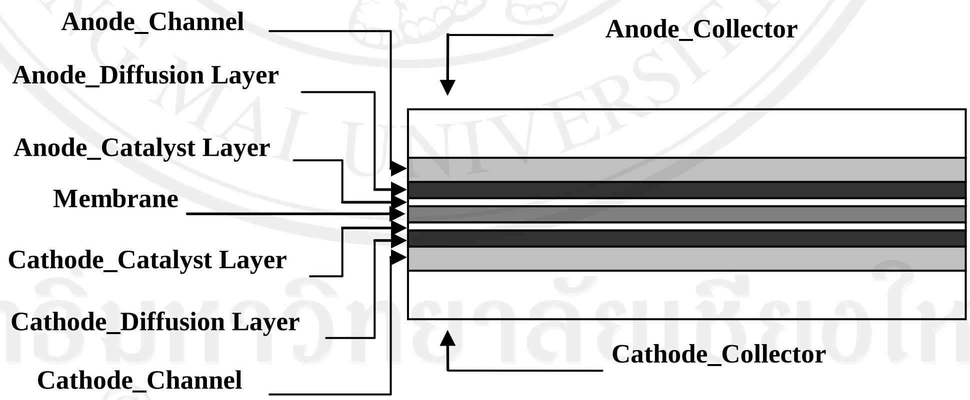


Figure 4.1 Cross-section of Proton Exchange Membrane Fuel Cell

Another very importance of building numerical modeling is grid, which used to calculation in model. Structured grid use in research, it is rectangular grid and appropriate use of the area where the study will be divided into a fine grid where it can affect more than education is shown in table 4.1 and figure 4.2

Table 4.1 Grids in PEMFC Modeling

Object	Grids (node)
width x length x depth of flow channel	5 x 47 x 5
width x length x depth of rib	5 x 39 x 5
width x length x depth of gas diffusion layer	204 x 47 x 5
width x length x depth of catalyst layer	204 x 47 x 5
width x length x depth of membrane	204 x 47 x 5

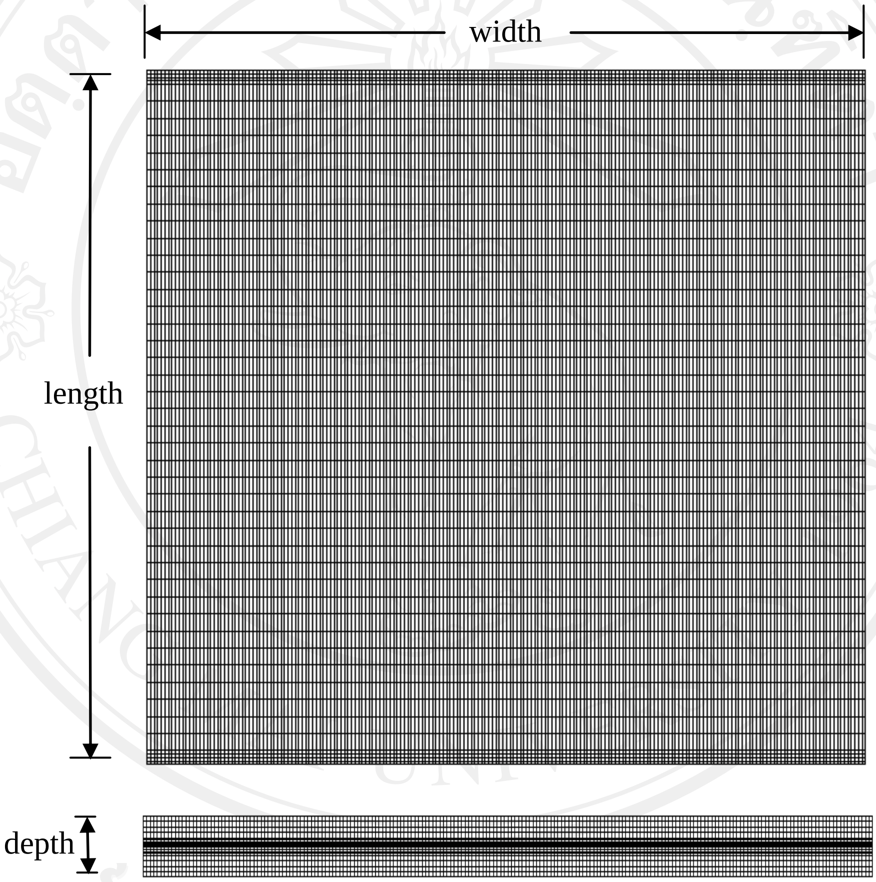


Figure 4.2 Grid in PEMFC modeling

There are building model and grid for processing in finish, the next step is setting properties and boundary condition in cases. In setting properties of PEMFC modeling is divide in each section allow component of PEMFC, but it same temperature all cell. In this research setting properties and boundary conditions is close experimental set up, which divide conditions for processing as follow:

1.Polar Plate or Collector

Polar plate is solid phase. It has density 2698.9 kg/m^3 and specific heat is 900 J/kg-K and thermal Conductivity is 210 W/m-K. The polar plate has wall, inlet and outlet, which there are properties;

a. Inlet

Inlet area of numerical modeling flow field has inlet on top flow field channel. In anode side give hydrogen gas and cathode side give oxygen gas, which it have flow rate is 200-500 cm^3/min. Temperature of gas is 60-80 ^oC. It shown in figure 4.3

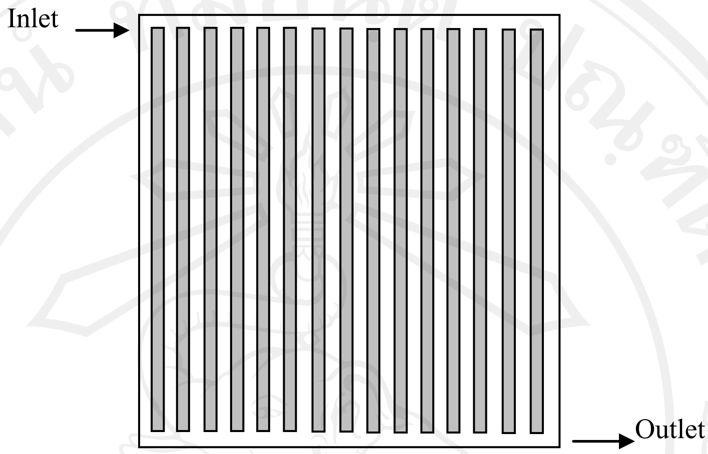


Figure 4.3 Location of inlet and outlet on flow field

b. Wall

In this boundary condition is solid surface, which fluid is not through. To setting flow rate is zero (no slip) and isothermal is 60-80 ^oC. Voltage on back surface between anode side and cathode side is 0.1-1.1 voltage.

c. Outlet

Boundary condition of outlet has constant pressure (ambient pressure) and temperature

2. Gas channel

Gas channel is fluid, which its properties are density is calculated out of ideal gas law, inlet mixtures define mass fractions of chemicals (H_2, O_2, N_2, H_2O) at inlets. For anode (H_2) saturated with H_2O mass fraction of H_2 is around 1.3% and for cathode (air) saturated with H_2O water mass fraction it is 25-30%.Fluid viscosity is calculated using mixture kinetic theory, specific heat via JANNAF tables for mixtures and thermal conductivity is calculated for const Prandtl number or out of kinetic theory for a given mixture.

3. Catalyst Layer

Catalyst layer is fluid and porous media. In cathode or anode have chemical reaction, which anode side have anode reaction is $0.5H_2$ -> H(L) and cathode side have cathode reaction is $0.25O_2$+H(L) -> $0.25H_2O$. It has Surface to Volume Ratio =1000, Tortuosity =1.5, sigma solid=53, Average pore size = 1.E-6, Heat conductivity solid = 200, Porosity = 0.4 and permeability = 1E-11.

4. Gas Diffusion Layer

Gas Diffusion Layer has fluid and porous media properties, which same as catalyst layer, but S/V=0 and no reactions, fluid electrical conductivity =1E-20

5. Membrane

Membrane has fluid and porous media properties. It have Solid sigma 1E-20 1/Ohm-m, S/V ratio = 0, no surface chemistry, diffusivity = Bruggman model, Tortuosity = 5, average pore size = 1.E-6, heat conductivity solid = 200 W/mK, Porosity = 0.28, permeability 1E-18 m^2

When setting all properties and boundary condition of numerical modeling are finish, the next step is processing for process to need answers. Finally, pre-processing is last step for result and present of answer.

4.2 Experimental Methods

4.2.1 Test Station and Control System of Proton Exchange Membrane Fuel Cell

Test station and control system are tools which can be control and set dependent parameters for running fuel cell and can be collect experimental data. Its have 2 parts are hardware and software. The test station and control system have necessary instrument to control flow rate, temperature, pressure, humid and current. Designing of fuel cell test station in this research as shown in Figure 4.4 is composed by these apparatuses as follow:

i) Mass flow rate control
ii) Temperature control
iii) Pressure control
iv) Humidity control
v) Electronic load

Requirement for the other operating parameters can be prescribed based on the maximum power output of 300 W. Size requirements must be set for the gas mass flows, gas temperatures, the fuel cell operating temperature, gas pressure and gas humidity levels. Table 4.1 shows the maximum design criteria and these criteria are discussed more detail in the following sections.

Table 4.2 Design criteria for PEM fuel cell test station

Criteria	Minimum	Maximum
Power	0.1W	300 W
Mass flow control		
H_2	5 sccm	500 sccm
O_2	5 sccm	500 sccm
Temperature control	Room temperature	70 ^oC
Pressure control	Atmospheric	400 kPa gauge
Humidity temperature control		
H_2	Dry gas	100 ^oC
O_2	Dry gas	100 ^oC
Data acquisition		
Voltage	0.04 V	10 V
Pressure	0 psig	100 psig
Temperature	0 ^oC	100 ^oC

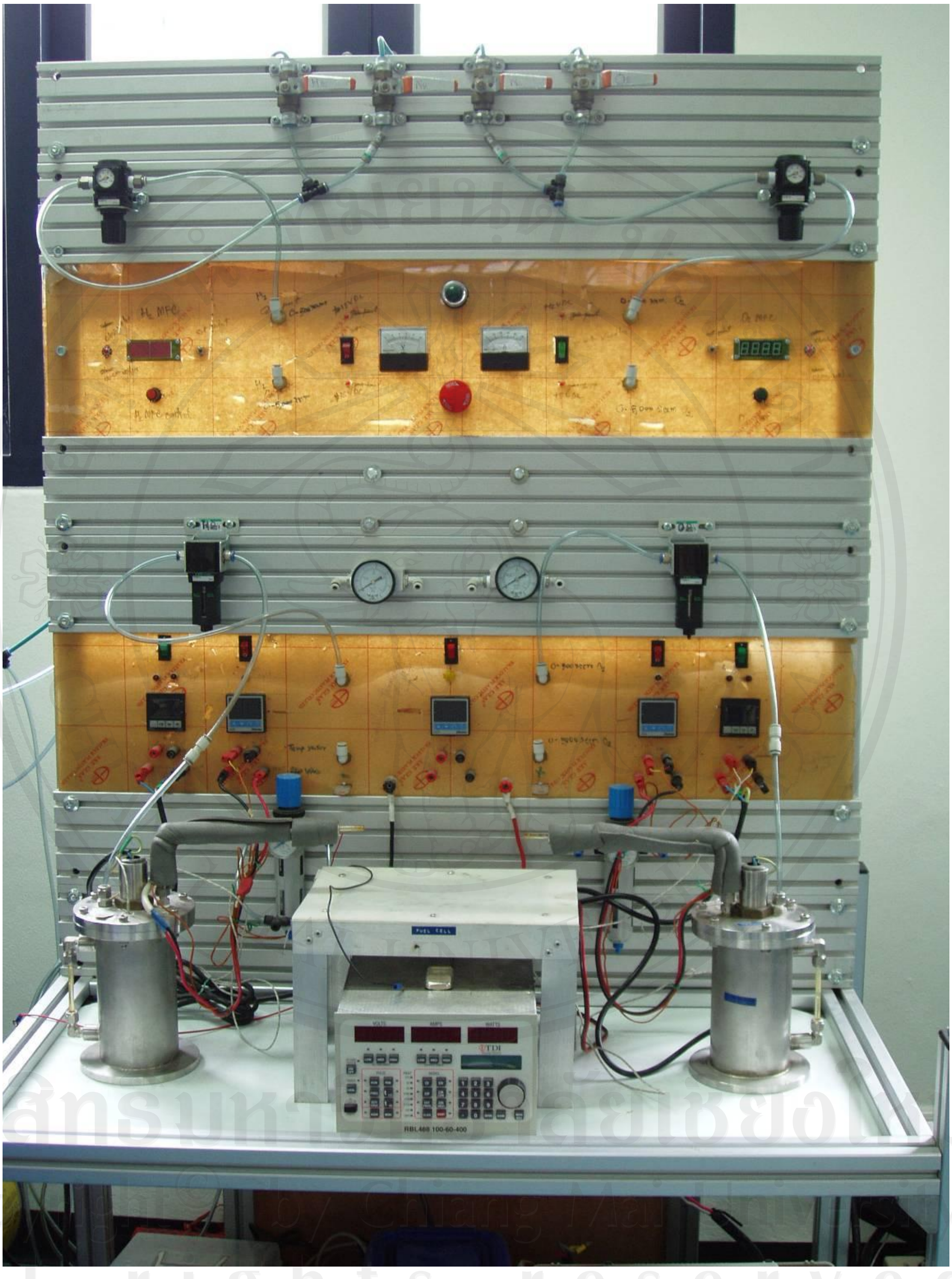
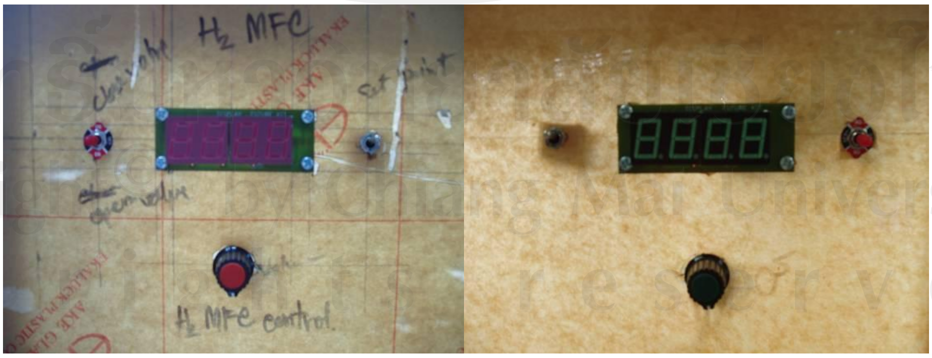


Figure 4.4 Fuel Cell Test Station in Mechanical Engineering, Chiang Mai University

i) Mass flow rate control

Current density has been built by PEMFC that it has dependent flow rate of hydrogen and oxygen. Flow rate of hydrogen vary with current which it can calculate volume of hydrogen for produce current density called hydrogen consumption rate. Mass flow controller has action to control flow rate that it has specificity for use with each type of gas shown in figure 4.5. The range of flow rate in this research use 200 – 500 cm^3/min. Flow rate control system consist of mass flow controller, gas manually control system and Gas Filter. Mass flow controller was used MKS, Type MB-100 mass flow controllers, which capable of metering flows greater than of full scale. This condition resulted in minimum flows of 5 sccm for both reactant gases. Both fuel and oxidant gases from the pressurized tank are measured and controlled with mass flow controllers. These devices are gas manually controlled system in figure 4.6 to adjust the amount of reactants flow rate and display the actual flow rate in the same time. Gas filter has functions for trap dust in gas before inlet cell, it is show in figure 4.7.

Figure 4.5 Mass flow controller



(a) (b)

Figure 4.6 Gas Manually Control systems (a) hydrogen controller (b) oxygen controller

Figure 4.7 Gas Filter

ii) Temperature control

Proton exchange membrane fuel cell has temperature operation is 60-80 ^{o}C, so heat Control system design is comprehensive this temperature. It use heat plate in this system for heat fuel cell and has thermocouple is automatic control temperature in the required range of work. The minimum temperature criteria of this test are room temperature (approximately 25 ^{o}C). The commercial temperature controllers were used in this fuel cell test station because of their attractive on durability and reliability with small compact design.

a) b) c)

Figure 4.8 a) Heat Control System of Fuel Cell b) Heat Control System of Humidifier c) Heat plate 220 Volt 60 Watts

iii) Pressure control

In operate proton exchange membrane fuel cell is atmosphere of Hydrogen and oxygen. The pressure requirements have a similar logic to the temperature requirements mentioned above. The typical pressure limit for PEM fuel cell is approximately 400 kPa gauge. Similar to the temperature criteria, the minimum pressure is atmospheric pressure. The pressure transducers were used to measure the reactant gases pressure level in range of 0 – 100 psig. Pressure regulators are show in figure 4.9

a) b)

Figure 4.9 a) Inlet Regulator b) Outlet Regulator

iv) Humidity control

Humidity is importance variable in conduct proton cross membrane. The appropriate humidity can help fuel cell for good performance. Humidifier tank is shown in figure 4.10. But the water balance of a fuel cell is one of the most difficult obstacles to overcome. The addition of too little water to the gas stream can dry the membranes and cause serious damage. On the other hand, too much water in the gas streams can lead to flooding, which prevents the transport of gas to the reaction sites and limit performance. At the present time, humidification of the gases is the best way of controlling the water balance in the fuel cell. The humidifier in this study was designed by using external water tank filled with distilled water. The vapor is generated by heating on the water tank. The dry reactant gases from compressive tank receive the humidity in the water tank, which are became humid gases. The mixture gases are saturated in that heating temperature before entrance to the fuel cell stack. The relative humidity of reactant gases after entrance to the fuel cell is dependent on the stack operating temperature at that time. If the temperature of stack is higher than the humidifier, the relative humidity is lower than 100%. If the temperature of stack cell is lower than humidifier, the vapor was condensed in the flow field channels. So, the humidity parameter in this study can be adjusted by control the temperature of humidifier at that fuel cell stack operating temperature.

Figure 4.10 Humidifier tank

v) Electronic loads

Electronic Loads used to find performance of fuel cell. It is build loads for test which it is similar adjustment resistor for pull out electric from fuel cell. Electronic load system shown in figure 4.11 and 4.12 is driving force the entire fuel cell. Fuel cells are low voltage and high current devices, and the electric load must have the capability to measure and draw loads such as this. In this study, we used the RBL488 Series Electronic Loads for fuel cell performance test. The RBL488 Series offers the selectable mode such as constant current mode (CI), constant voltage mode (CV), constant power mode (CP) and constant resistance mode (CR), which cover our requirement in this fuel cell performance test. The measurement ranges and accuracy of the electronic load are following:

- Maximum current range: 60 A, 30 A and 6 A
- Current accuracy: ± 0.50 %
- Current resolution: ±0.025 %
- Maximum operating voltage: 100 V, 50 V and 10 V
- Voltage accuracy: ± 0.50 %
- Voltage resolution: ±0.025 %

Figure 4.11 Voltmeter and Amp meter for Electronic Load

Figure 4.12 Electronic load

4.2.2 Experimental Design

The experimental design is essential to understand the parametric effects on design flow fields and fuel cell performance of PEM fuel cell. In this section, a set of experimental tests was scheduled and the experimental procedure was also presented for each run of fuel cell experimental tests.

4.2.2.1 Test scheduling

The experimental schedules were performed on single cell. Each set of experimental test was started with the pre-condition process. The pre-condition or break-in is typically used upon restarting a cell before each round of testing. Such procedures involve a stabilization period at a specified load and cell conditions in order to bring the cell to a predictable state of hydration before testing is resumed.

4.2.2.2 Gas flow rate control

The anode and cathode gas flow rate can contribute to water removal. The gas flow rates were conducted at 500 cm^3/min. These 3 runs were operated on ambient pressure and cell operating at room temperature and heating. Both reactant gases were humidified.

4.2.2.3 Temperature control

A single cell was operated at the condition of atmosphere pressure, hydrogen and oxygen gas flow rate of 500 cm^3/min. There was external humidifier supplied to the both side of PEM fuel cell and water was generated from the fuel cell reaction. The operating temperature control was conducted at temperature, 60 ^oC, 70 ^oC and 80 ^oC with a total of 3 runs.

4.2.2.4 Pressure control

The reactant operating pressure was also conducted to observe its effect on fuel cell performance and water management inside cell. The temperature of the fuel cell and the saturation temperatures (anode and cathode side) were varies at 60-80 ^oC. The operating pressures were varied from atmospheric pressure to 15 psig within intervals of about 5 psig, and the same pressure was imposed on both the anode and cathode side. These 3 runs of pressure variables were operated while the flow rate of gas fuel.

4.2.2.5 Humidification control

The second point concerns the effect of the equal variation of the reactant saturation temperatures while fixing the fuel cell operating temperature at 60 ^oC. The reactant humidity levels were conducted on humidified 60 ^oC, 70 ^oC and 80 ^oC with a total of 3 runs under atmospheric pressure.

4.2.2.6 Dynamic current mode

The polarization curve is the most important characteristic of a fuel cell, which represents the cell voltage-current relationship as mentioned before in Chapter 2. This section is concerned with the achievement for polarization curve of the fuel cell in difference flow fields. The dynamic current mode was used to control the current, which is generated by fuel cell and also related with fuel cell voltage. The received polarization curves were used as main criteria to prove the most proper method for flow filed designed in the fuel cell in this study.

4.2.3 Component of Fuel Cell

a) Graphite

Flow field was drilled inside Graphite. In this study, it use 3 types of flow field which compare with old fuel cell and new fuel cell are show in figure 4.13-4.15.

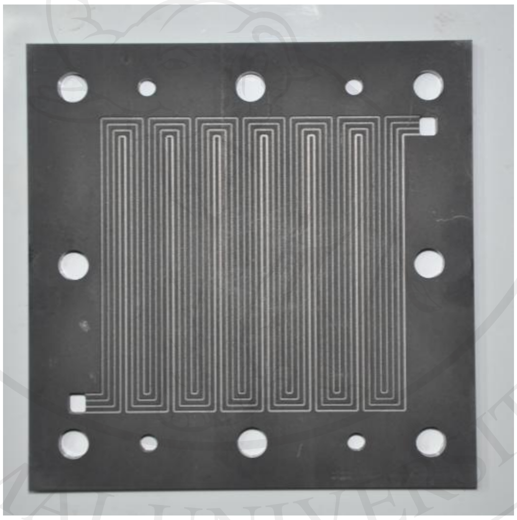


Figure 4.13 4 serpentine channels flow field

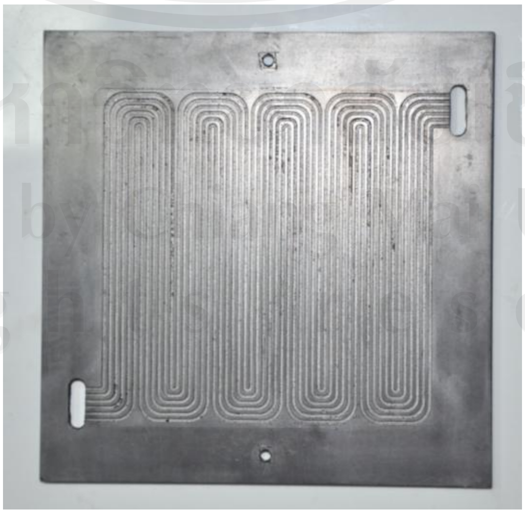


Figure 4.14 6 serpentine channels flow field

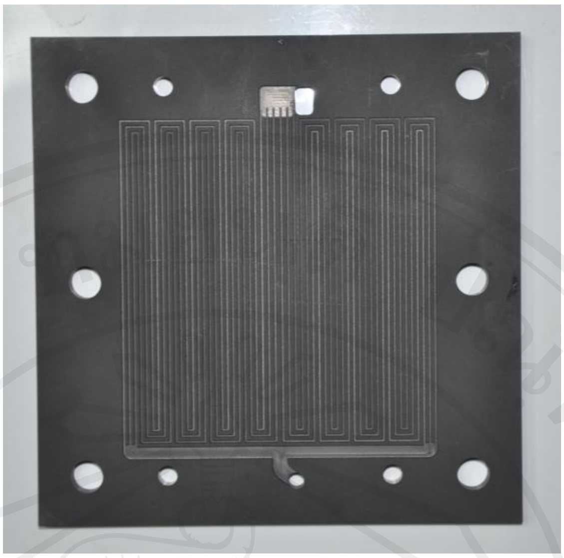


Figure 4.15 2 ways multi-serpentine channels flow field

b) MEAs

The MEAs used in this work were a combination of Nafion 117 and catalyst loadings Pt of 6.0 mg/cm^2. It is show in figure 4.18.

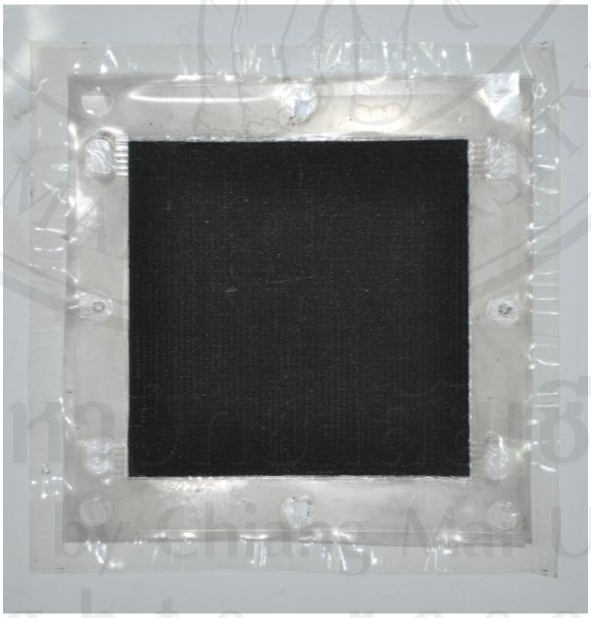


Figure 4.16 MEAs

c) Collector Plate

Collector plates made from brass are show in figure 4.19.

Figure 4.17 Collector plate

d) End plate

Collector plates made from stainless are show in figure 4.20.

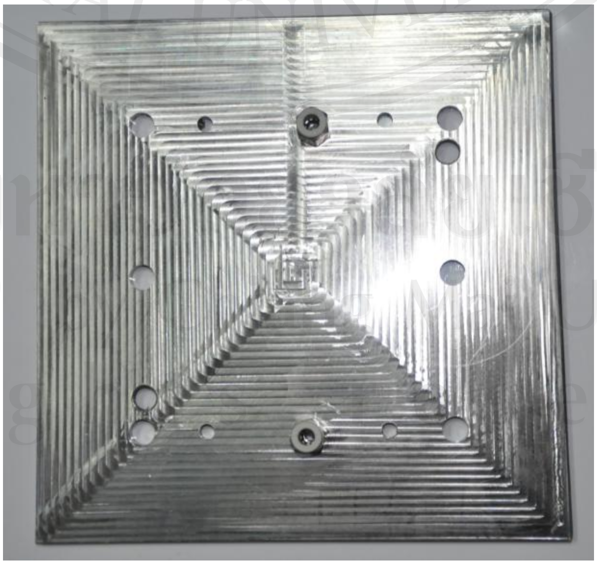


Figure 4.18 End plate

e) Single cell

All components could be assembly to single cell, shown in figure 4.21

Figure 4.19 Single cell