CONCEPTUAL STUDY OF HYDROGEN POWERED WHEELBARROW USING FUEL CELL

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Report submitted in partial fulfillment of the requirements for the award of Bachelor of Mechanical Engineering with Automotive Engineering.

Faculty of Mechanical Engineering

UNIVERSITY MALAYSIA PAHANG

JUNE 2013

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

We certify that report entitled 'Conceptual Study of Hydrogen Powered Wheelbarrow using Fuel Cell' is written by Muhamad Afiq Bin Saukit with matric number MH09048. I have examined the final copy of this paper report and in our opinion; it is fully adequate in terms of scopes and quality for the award of the degree of Bachelor in Mechanical Engineering with Automotive Engineering. I herewith recommend that it be accepted in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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I hereby declare I have checked this report, which written by Muhamad Afiq Bin Saukit, and in my opinion, this report project is adequate in terms of scopes and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this report is my own, except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any other Degree and is not concurrently submitted for award of other degree.

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ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisors Prof. Dr. Shahrani Bin Anuar for providing this interesting and exciting topic and then providing his guidance, assistance and encouragement throughout the duration of the project. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments.

To all my committee members, thanks for the comments and suggestions given which is crucial for the successful completion of this study.

Special thanks to my lovely parents for their support, love, dream and sacrifice throughout my life. I would like to appreciate their devotion, support, and faith in my ability to attain my goals.

DEDICATION

Specially dedicated to

My beloved family and those who have

Encourage and always be with me during hard times

And inspired me throughout my journey of learning

ABSTRACT

The design, fabrication, and testing of a prototype of a wheelbarrow powered by a fuel cell is reported. Usually wheelbarrow does not have motor and need more energy to use. An conceptual study on this project is the idea on how the project can be done properly. The compact systems consist of hydrogen generator, fuel cell, motor and the wheelbarrow. The project focused on the conceptual study of system in the fuel cell that can be powered wheelbarrow. This research define the power of electric motor that need to move 80 kg load is 0.082 kW for the minimum and 0.22 kW for the maximum power with velocity 2.78 m/s. Hydrogen generator cost also has been define, hydrogen cost for this project is RM 39.90. Number of molar and molar mass of hydrogen has been calculated for move 80kg load. The number of molar hydrogen is 0.149 gmol/hr, and the number of molar mass of hydrogen is 3.003 x $10^{-4}\,\frac{kgH_2}{hr.A}$

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ABSTRAK

Reka bentuk, fabrikasi, dan pengujian prototaip kereta sorong yang bergerak menggunakan hidrogen akan dibangunkan untuk tujuan penyelidikan. Kebiasaannya kereta sorong tidak mempunyai motor dan memerlukan tenaga yang banyak jika hendak digerakkan.Penyiasatan tentang pengajian konsep bagi projek kereta sorong menggunakan 'fuel cel'teah dijallankan bagi mengenalpasti cara untuk membina projek tersebut. Sistem ini terdiri daripada penjana hidrogen, *fuel cell*, motor dan kereta sorong. Penjana hidrogen dan *fuel cell* akan difabrikasikan dengan menggunakan teknik mekanikal terkini. Projek memberi tumpuan kepada penerangan tentang sistem yg perlu dihasilkan untuk menggerakkan kereta sorong menggunakan kuasa dari *fuel cell*. Projek ini menyatakan kuasa yang diperlukan oleh motor eletrik untuk menggerakkan 80 kg beban dengan kelajuan 2.78m/s ialah 0.082 kW untuk kuasa minimun dan 0.22 kW untuk kuasa maximun. Kos untuk penjana hydrogen juga dikenal pasti didalam kajian ini iaitu sebanyak RM39.90. Nombor molar dan nombor jisim molar untuk hydrogen turut dikenalpasti didalam penyiasatan ini bagi mengerakkan kereta sorong sebrat 80 kg. Nombor molar untuk hydrogan ialah 0.149 gmol/hr dan nombor jisim molar bagi hydrogen ialah 3.003 x $10^{-4} \frac{kgH_2}{hr.A}$

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LIST OF SYMBOLS

H_2O	Water
O_2	Oxygen
H_2	Hydrogen
F	Force
M	Mass
α	Acceleration
ρ	Density
kW	Kilowatt
μ	Coefficient of Friction
F_N	Normal Force
f_D	Drag Force
C_d	Drag Coefficient
T	Torque
r	Radius
N	Newton
mm	millimetre
rpm	Rotational per minute

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Wheelbarrow is one wheel transport device made of metal designed to reduce the workload by using a single rotating wheel. Wheelbarrow consists of a bucket (barrow) and two handles. Wheelbarrow is used at the construction site, gardening and landscaping to move heavy load to another place with a small amount of energy. For example in landscaping, wheelbarrow is used for transporting material from large pile to desired area, transporting smaller trees for carry fertilizers, and moving large top soil.

The wheelbarrow work mechanism is incorporated into a conventional load carrying device including a bucket portion, a pair of elongated handles supporting the bucket portion, and a front wheel. The tilting mechanism includes a frame adapted to being secured in a rearward extending location of the elongated handles and such that the bucket portion is disposed between the frame and the front wheel. Elongated supports are incorporated into the frame and, in combination with the front wheel, support the wheelbarrow upon a surface. The frame includes structure for establishing an angle or incline, relative to an uneven or peaked surface, and is actuated to facilitate tilting of the bucket portion about a longitudinal axis extending through the load carrying device. Moving becomes easier because of single wheel. Single wheel permits load up a plank ramp or along a path that is barely wide enough to stand on, while two wheels requires not only two paths or planks, but they must be of equal strength and curvature to keep the load from tipping [1].

Research of wheelbarrow by using fuel has not been done by other researcher. One of the key measures to reduce environmental pollution caused by automobiles is to introduce vehicles running by fuel cells, especially the proton-exchange membrane fuel-cell (PEMFC) vehicles. These types of vehicles are powered by a clean fuel namely fuel cell [2, 3]. Besides PEMFC vehicles being environmentally clean, they operate at low temperatures and achieve quick responses; they are at least30% more e□cient than IC vehicles since they are not limited by the Carnot Cycle [4].

Fuel cell is a device that converts chemical energy into electrical energy, water, and heat through electrochemical reactions. Fuel and air react when they come into contact through a porous membrane (electrolyte) which separates them. This reaction results in a transfer of electrons and ions across the electrolyte from the anode to the cathode. If an external load is attached to this arrangement a complete circuit is formed arrangement, a complete circuit is formed and a voltage is generated from the flow of electrical current.

The voltage generated by a single cell is typically rather small (< 1 volt), so many cells are connected in series to create a useful voltage. Because the intermediate steps of producing heat and mechanical work typical of most conventional power generation methods are avoided, fuel cells are not limited by thermodynamic limitations of heat engines such as the Carnot efficiency. In addition, because combustion is avoided, fuel cells produce power with minimal pollutant.

1.2 PROJECT BACKGROUND

In this project, focuses will be study conceptual on the design and development of fuel cell for wheelbarrow. The details phases of the new fuel cell development, from concept design consideration.

Next the design concept or sketching the prototype of a fuel cell for wheelbarrow will be evaluated in order to select the best design and drawn using Solidwork or AutoCAD software's prior to the final design being fabricated but before that the system for fuel cell need to be sketched in order to see the whole system thoroughly.

This process will be followed by suggestion on process in order to develop the hydrogen generator according to the design. Once the conceptual fabrication process study finished, the hydrogen generator, fuel cell and the motor will be attached to the wheelbarrow. The test run will be conducted to investigate if the systems functioned well.

1.3 PROBLEM STATEMENT

Usually wheelbarrow does not have a motor and need more energy to use. The motivation for this research is, to install the fuel cell that can make the wheelbarrow function well with less human work involved. A compact design of the fuel cell systems will be designed and installed at the wheelbarrow. An actual conceptual study on this project is the idea on how that project can be done properly.

Hydrogen generator is important component to the system, in which if the generator can produce more hydrogen, then fuel cell can produce more electric. The system should have continues hydrogen supply to ensure the motor can work in a long period of time. The research will concentrate on the production of hydrogen generator as well as the fuel cell system.

1.4 PROJECT OBJECTIVES

The main objective of this project is to investigate conceptual system of compact hydrogen fuel cell that can be powered wheelbarrow.

1.5 PROJECT SCOPE

The scope of this project is:

1. Research about fuel cell
2. Design a compact fuel cell system that can be fitted in to wheelbarrows.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is a review about the system to install in the wheelbarrow, the system that contains hydrogen generator, and fuel cell part with some research and new improvement to get more electricity taken from fuel cell to the motor.

2.2 THE POLYMER ELECTROLYTE MEMBRANE (FUEL CELL)

The first fuel cell was created by William Grove in 1839, with four large cells that contain hydrogen and oxygen produce electric power. NASA makes commercial fuel cell to use in the Apollo space flight. Fuel cell research and development has been developed actively start from 1970 [5].

Generally fuel cell acts as a converter to convert chemical energy into electrical energy, and heat through an electrochemical reaction. Fuel and air react when they come into contact through a porous membrane (electrolyte) which separates them. Electric was generated by transfer of and ions across the electrolyte from the anode to the cathode. If an external load is attached to this arrangement a complete circuit is form arrangement, a complete circuit is formed and a voltage is generated from the flow of electrical current.

The fuel cell produces heat and mechanical work typical of most conventional power generation methods are avoided; fuel cells are not limited by thermodynamic limitations of heat engines such as the Carnot efficiency. Fuel cell can ovoid combustion and at the same time can produce power without air pollution. However, unlike batteries there oxidant in fuel cells must be continuously replenished to allow continuous operation.

Many types of fuel cell use in the world, Table 2.1 below shows the type of fuel cell, with efficiency, operating temperature and application of fuel cell.

Table 2.1: Show list of fuel cell type

Type	Efficiency	Operating Temperature	Use
Polymer electrolyte membrane (PEMFC)	40% / 80%* with cogeneration	175º F	Transportation – cars, buses, boats, trains, scooters, bikes Residential – household electrical power needs Portable – laptop computers, cell phones, medical equipment
Direct methanol (DMFC)	40%	120 - 150º F	Portable – cell phones, laptop computers, vacuum cleaners, highway road signs
Alkali (AFC)	60% / 80%*	250 - 500º F	NASA space program – space vehicles
Phosphoric acid (PAFC)	40% / 80%*	300 - 400º F	Landfill/wastewater treatment facilities – To generate power from methane gas

Source: Criss (2003)

Usually fuel cell contain three main component, see Figure 2.1: the first one is unit cells, that is the electrochemical reactions take place, second component is stacks, stack is the individual cells are modularly combined by electrically connecting the cells to form units with the desired output capacity, and the last component is balance of plant which contain components that provide feed stream conditioning including a fuel processor if needed, thermal management, and electric power conditioning among other ancillary and interface functions[6].

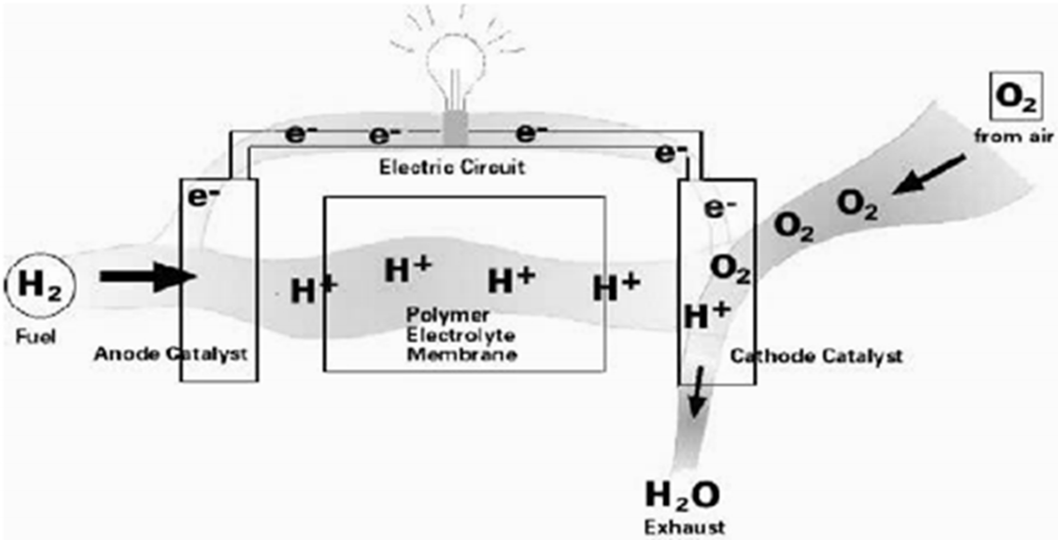

Figure 2.1: Basic concept of fuel cell

Source: Carrette, L. (2001)

The fuel cell has some different between galvanic cell battery and fuel cell but the main objective if still same is to generate electricity. Usually battery stores the chemical reactants, such as metal compounds like lithium, zinc or manganese. After used in some period of time, battery should be recharged or throw away the battery. Fuel cell creates electricity through reactants (hydrogen and oxygen) stored externally. The fuel cell produces electricity as long as it has a fuel supply. In short, a fuel cell vehicle is refueled instead of recharged [7]. The different of operating system shown in Figure 2.2:

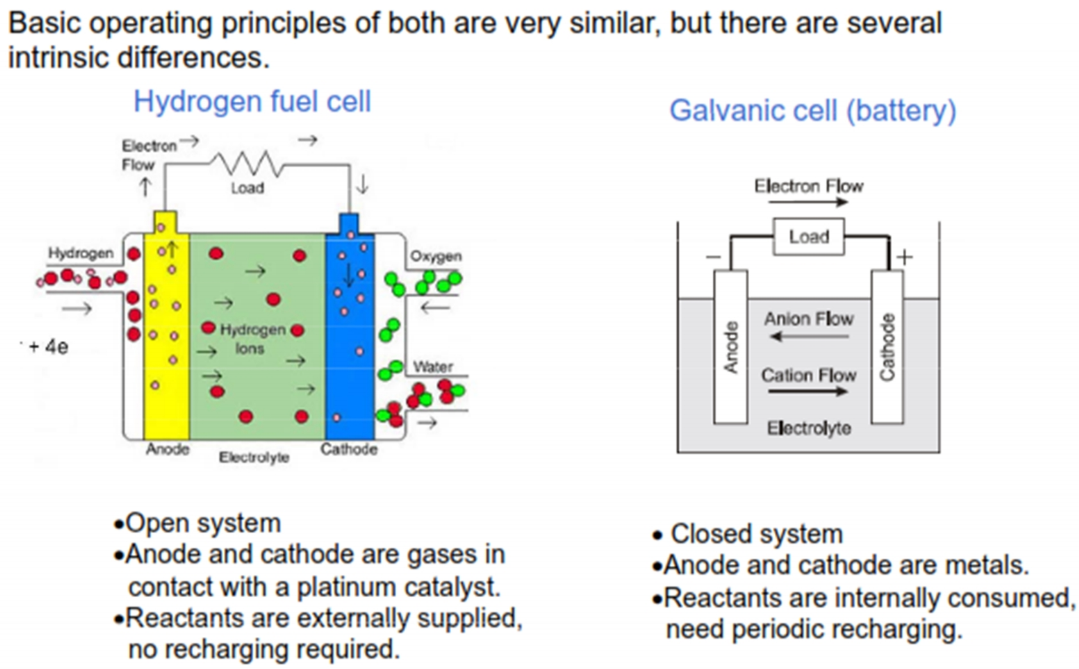

Figure 2.2: Fuel cell vs. battery

Source: Carrette, L. (2001)

2.3 ELECTRODES

All electrochemical reactions consist of two separate reactions: an oxidation half-reaction occurring at the anode (positive terminal) and a reduction half-reaction occurring at the cathode (negative terminal).

The anode and the cathode are separated from each other by the electrolyte, the membrane. In the oxidation half-reaction, gaseous hydrogen produces hydrogen ions, which travel through the ionically conducting membrane to the cathode, and electrons which travel through an external circuit to the cathode [8].

Reduction half-reaction, oxygen, supplied from air flowing past the cathode, combines with these hydrogen ions and electrons to form water and excess heat. These two half-reactions would normally occur very slowly at lower operating temperatures, typically 80 ûC, of the polymer electrolyte membrane fuel cell. Thus, catalysts are used on both the anode and cathode to increase the rates of each half-reaction. The final products of the overall cell reaction are electric power, water, and excess heat. Cooling is required, in fact to maintain the temperature of a fuel cell stack at about 80 ûC. At this temperature, the product water produced at the cathode is both liquid and vapor. This product water is carried out of the fuel cell by the air flow.

Membrane electrode assembly (MEA) is made up with the 0.025 mm thick polymer membrane and the 0.1 mm thick diffusion media layer on each side of the polymer membrane, between two MEAs there is a BPP, which consists of two pieces of forming thin plates jointed together, shown in Figure 2.3. Each plate is made of stainless steel with the 0.6 mm depth flow channels and the total thickness of one BPP is about 1.4 mm including the thickness of metal sheets [13].

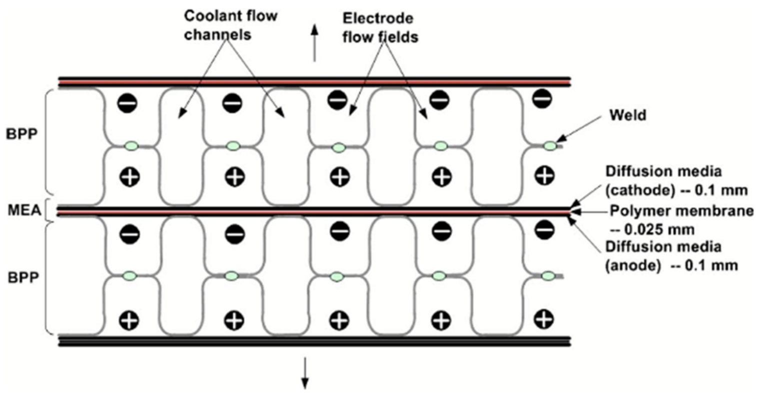

Figure 2.3: Sketch of assembly Proton Electron Membrane fuel cell stacks, based on metallic thin.

Source: Peng, L (2010)

2.4 BIPOLAR PLATE

Bipolar plates are conductive plates in a fuel cell stack that act as an anode for one cell and a cathode. Bipolar plates can be made of metal, carbon or conductive composite polymer. The polymer is the plastic plates are also in development [20].

Bipolar plates should have a number of functions within the fuel cell stack:

1. Separating gases between cells (the reaction gases and water exhaust)
2. Providing a conductive medium between the anode and cathode
3. Providing a flow field channel for the reaction gases
4. A solid structure of the stack
5. Transferring heat out of the cell

Requirement of bipolar plate for fuel cell:

1. Impermeable to gases in a Proton Exchange Membrane cell, hydrogen and oxygen
2. Good electrical conductivity
3. A balance between conductivity, strength, size and weight – weight is more of concern for transportation and portable applications
4. Resistance to corrosion
5. Easy to manufacture in large quantities
6. The flow field must provide uniform distribution of the reaction gases over the active area to ensure even and efficient power production

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will describe about the overall process of the methodology in this project from beginning to end of the project. There are three main processes that start with, collecting the data, design the system, and result analysis. All the processes will be described in this chapter by following the chart. During this part, every information and data will be gathered together and concluded according to the objectives and scope of the project.

The project method is basically referred to design and develop new fuel cell and system can be used in a wheelbarrow. Create of new fuel cell need more study and research is not simple step process since it require many procedures and step to follow.

3.2 FLOW CHART

Flow chart is an important method in order to make sure the project can be done on time. Based from the flow chart, the project started with the literature review on the project. Research was made through journals, webs, books and other related sources.

The design of the fuel cell and hydrogen generator is conducted after all information about the project is gathered. Required parameters need to be defined as a design factor. Experiment start after work piece electrode, stack of fuel cells was prepared. Then collect the data and analyses it. The flow Chart project shows in Figure 3.1:

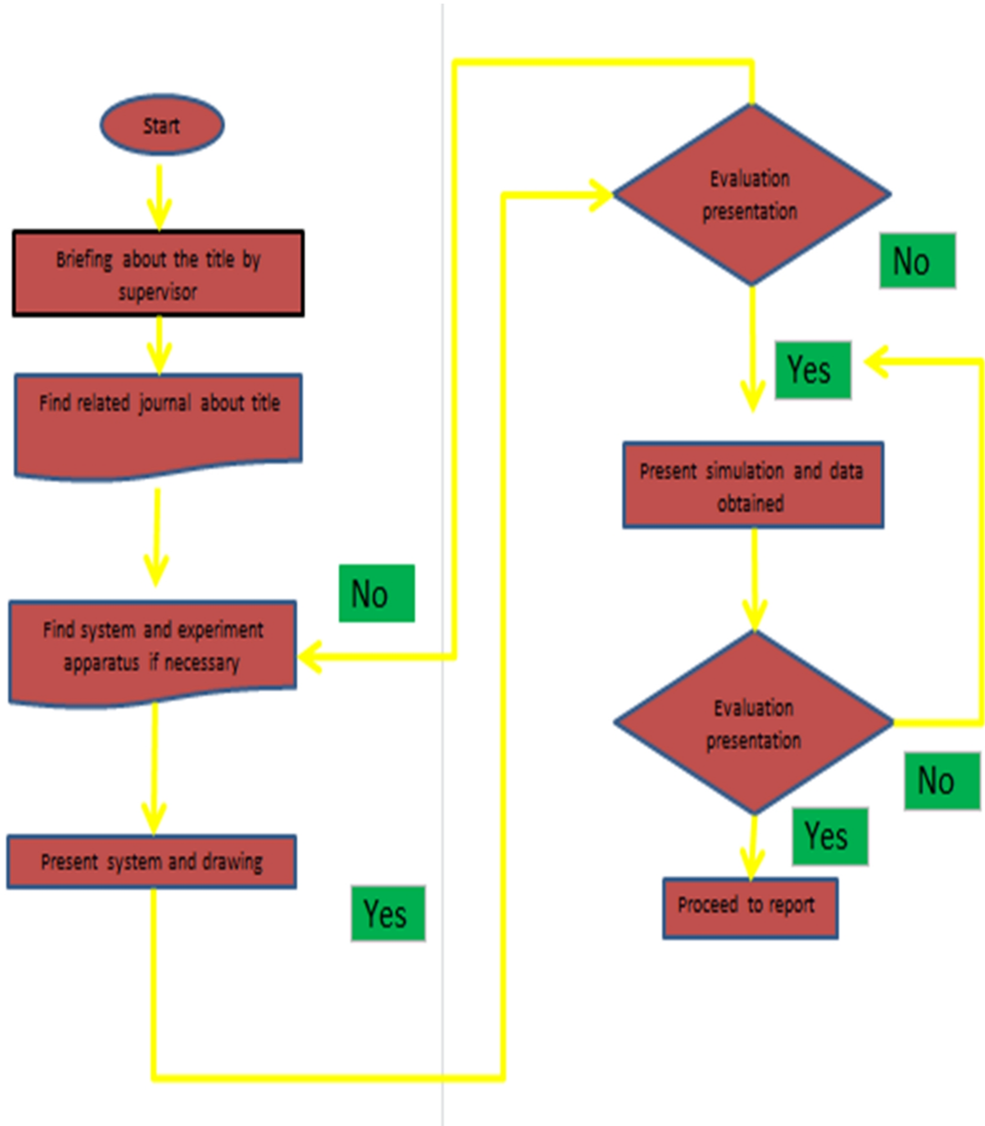

Figure 3.1: Flow Chart of the Project

3.3 Grant Chart

Grant chart is the tables that contain the list of activities have been done to make sure the project follow their due date. Table 3.1 shown grant chart of this project.

Table 3.1: Grant Chart of this project

Project Scope	Week												
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13
Journal Research													
Components Parameters													
System Design													
Final Report Presentation													

3.4 DESCRIPTION OF THE METHODOLOGY

3.4.1 Hydrogen Generator

There are many types to produce hydrogen from renewable energy sources. It can be produced from a variety of biomass feed-stocks, such as agricultural crops and wastes, sewage sludge or municipal solid waste, by thermo-chemical (pyrolysis or gasification) or biological processes that break down complex organic molecules into simpler molecules including hydrogen**.**

Hydrogen produces from renewably generated electricity, via electrolysis, to split water into hydrogen and oxygen. Wind and solar resources are much larger than biomass resources and it would be possible to produce electrolytic hydrogen in most part. This provides a way of storing renewable generated electricity on a much larger scale than is currently possible with existing battery technology.

In this project, electrolysis is the best way to get hydrogen for running the fuel cell. Electrolysis a method of separating elements by passing an electric current through a compound, used in various industrial applications such as removing copper from its ore. It is also used to separate hydrogen and oxygen from water. Electrolysis isn't the most efficient way to obtain hydrogen.

Electrolysis is the process that separates water into alkaline and acid water by passing an electric current through an electrolyte. In electrolysis, positive ions migrate to the cathode (negatively charged electrode) and negative ions migrate to anode (positively charged electrode). The reactions occurring depend on electron transfer at the electrodes and are therefore redox reactions.

At the anode, negative ions in water may lose electrons to form neutral species (oxygen). Atoms of the electrode may lose electrons and go into solution as positive ions. In either case the reaction is an oxidation. At the cathode, positive ions in water can gain electrons to forum neutral species (hydrogen). Thus cathode reactions are reductions.

At negative electrode the product has been shown in the chemical equation, $2H_2O_{(l)} + 2e^- \rightarrow H_{2\ (g)} + 2\ OH^-_{(aq)}$, the product of this electrode is H_2 and 2 OH^-. Positive electrode water will go oxidation process, $2H_2O_{(l)} \rightarrow O_{2\ (g)} + 4H^+_{(aq)} + 4e^-$, and the product is oxygen and hydrogen. Figure 3.1 show the simple electrolysis process.

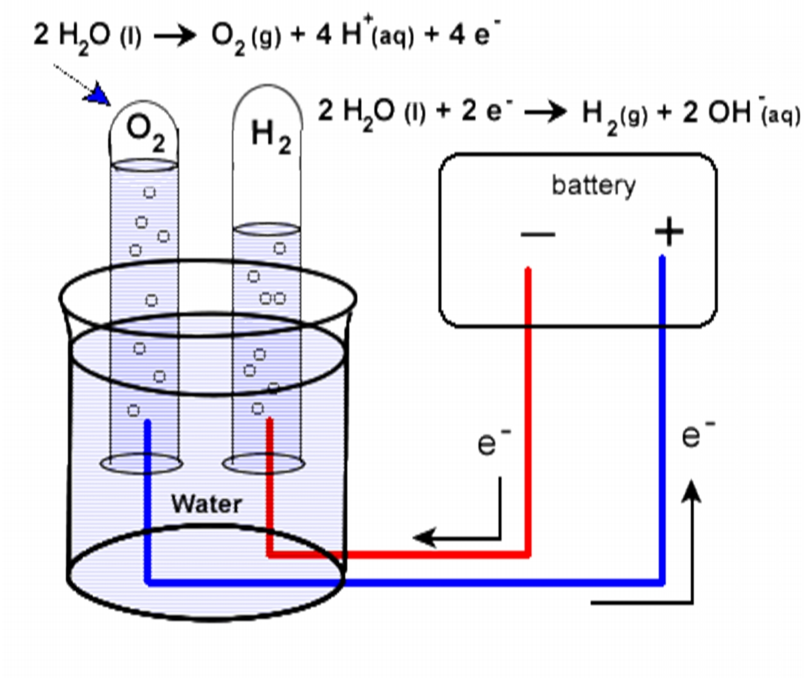

Figure 3.2: Example of simple electrolysis process.

Source: Gillet, A.C.,(1999)

3.4.2 Fuel cell

Fuel cells are self-contained power generation devices that are able to produce reliable electricity for residential, commercial, industrial and transportation applications. A fuel cell can convert hydrogen directly into electricity that can be used to power an electric.

Fuel cell consists of an anode (negative side), a cathode (positive side) and an electrolyte that allows charges to move between the two sides of the fuel cell. Electrons are drawn from the anode to the cathode through an external circuit, producing direct current electricity. As the main difference between fuel cell types is the electrolyte, fuel cells are classified by the type of electrolyte they use.

After some modification the original fuel cells design by using sulphonated polystyrene ion-exchange membrane as the electrolyte. Three years later another GE chemist, Leonard Niedrach, devised a way of depositing platinum onto the membrane, which served as catalyst for the necessary hydrogen oxidation and oxygen reduction reactions. This became known as the 'Grubb-Niedrach fuel cell'. GE went on to develop this technology with NASA and McDonnell Aircraft, leading to its use during Project Gemini. This was the first commercial use of a fuel cell. In 1959, British engineer Francis Thomas Bacon successfully developed a 5 kW stationary fuel cell. In 1959, a team led by Harry Ihrig built a 15 kW fuel cell tractor for Allis-Chalmers, which was demonstrated across the U.S. at state fairs. This system used potassium hydroxide as the electrolyte and compressed hydrogen and oxygen as the reactants. Later in 1959, Bacon and his colleagues demonstrated a practical five-kilowatt unit capable of powering a welding machine [15].

Bipolar plate is one of important plate that use in a fuel cell to create electricity, design of new bipolar plate was proposed to join the project. The design shown in Figure 3.2, red line represents to hydrogen in and out.

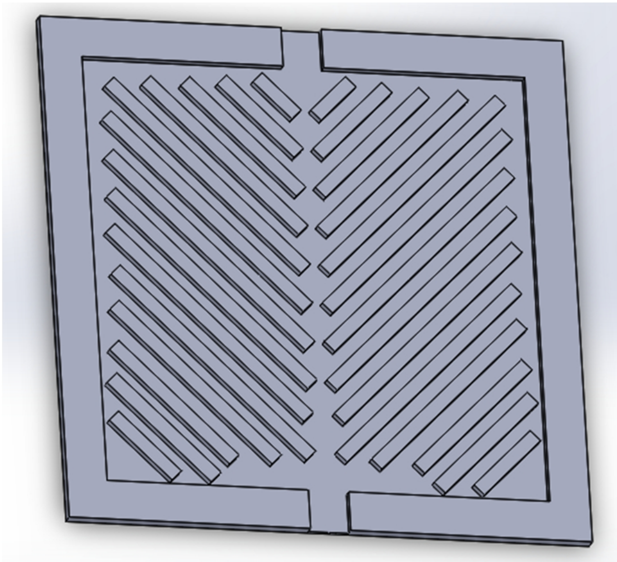

Figure 3.3: Bipolar plate design proposes in this project.

The most important part of the fuel cell is a proton exchange membrane fuel cell [16] (PEMFC) efficient frontier [17] design, a proton-conducting polymer membrane, (the electrolyte), separates the anode and cathode sides. This was called a "solid polymer electrolyte fuel cell" (SPEFC) in the early 1970s, before the proton exchange mechanism was well-understood.

Anode side, hydrogen diffuses to the anode catalyst where it later dissociates into protons and electrons. These protons often react with oxidants causing them to become what is commonly referred to as multi-facilitated proton membranes. Protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons (which have travelled through the external circuit) and protons to form water — in this example, the only waste product, either liquid or vapor.

Different components of a Proton exchange membrane fuel cell (PEMFC) are bipolar plates, electrodes, catalyst, membrane, and the necessary hardware [17]. The materials used for different parts of the fuel cells differ by type. The bipolar plates may be made of different types of materials, such as, metal, coated metal, graphite, flexible graphite, C–C composite, carbon–polymer composites [18]. The membrane electrode assembly (MEA), is referred as the heart of the PEMFC and usually made of a proton exchange membrane sandwiched between two catalyst coated carbon papers. Platinum a similar type of noble metals are usually used as the catalyst for PEMFC. The electrolyte could be a polymer membrane.

3.5 CONTROL SYSTEM

The system is starting with hydrogen generator. The hydrogen generator will react on electrolysis to produce hydrogen and oxygen. The hydrogen gases will be transferred to fuel cell. In fuel cell, electrochemical reaction will occur here the electron form the hydrogen will be extracted and the leftover hydrogen will react with air to produce water. The good thing about fuel cell is the emission where it the only emission is water and heat. The electricity will be transferred through the wire to the motor where it will rotate the motor and chain that connect between the motor and tire will rotate.

3.6 SOLID WORKS SOFTWARE SKETCHING

In this section shown design hydrogen generator and fuel cell stack, this design in early stage, and still not decided whether to use this design or not. The design of the hydrogen generator and fuel cell stack was shown in Figure 3.4and Figure 3.5.

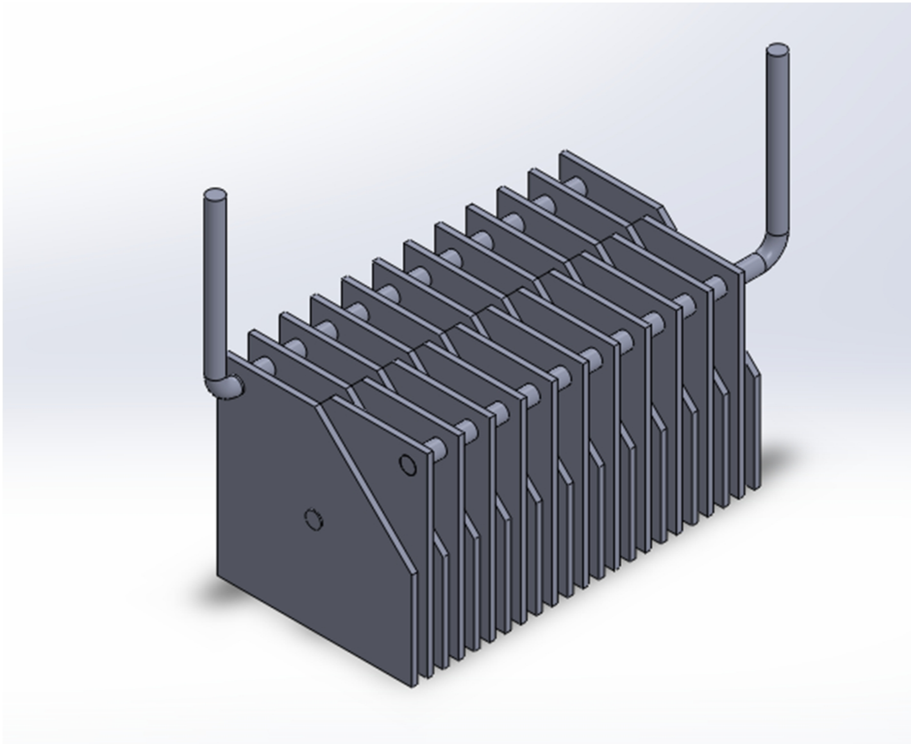

Figure 3.4: Hydrogen Generator stacks at early stage

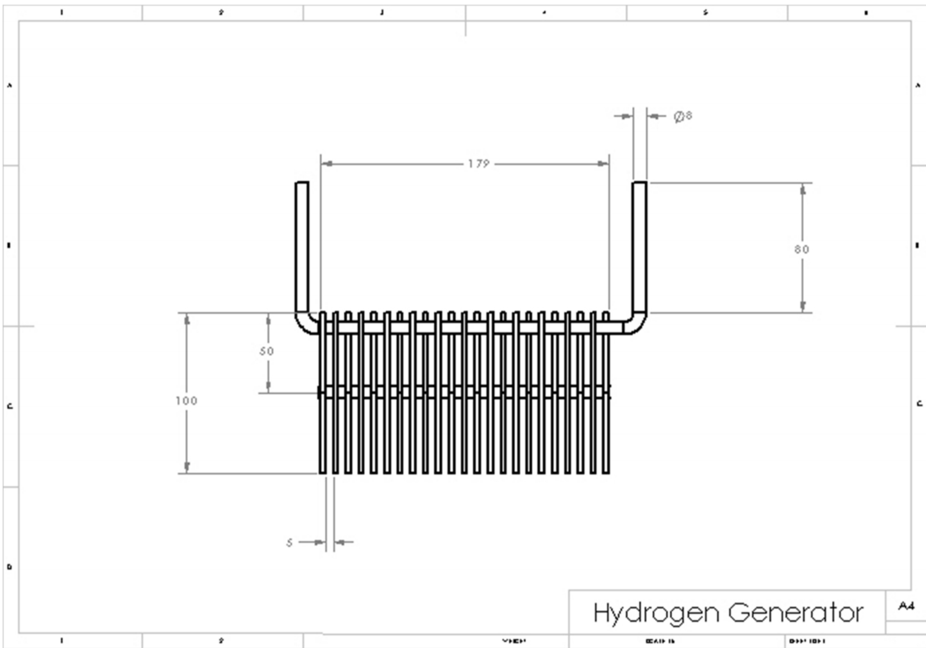

Figure 3.5: Hydrogen Generator stack in front view.

3.7 Engine Selection

The engine selection calculation was shown in this section, engine selection must be correct to give maximum power to wheelbarrows. Engine function is to convert electrical energy stored in the fuel cell to rotational mechanical energy output by the driveshaft. Calculation below just a sample of calculation that use to get power needed.

3.7.1 Theoretical Calculation

The suitable engine to use for the hydrogen powered bicycle can be determined by using the second Newton's Law equation.
The second Newton's Law equation:

$$F = m.a \qquad (3.1)$$

Where: F is Force to move the car
m is mass of the car and driver
A is acceleration of the car

The force that acting on the car is friction force by tire and road, shown in Figure 3.6, normal force and drag force can be calculated using the equation below:

$$f_\mu = F_N.\mu \qquad (3.2)$$

$$F_N = mg \qquad (3.3)$$

$$f_D = \frac{1}{2}\rho A C_d v^2 \qquad (3.4)$$

Where: f_μ is friction force by tyre and road
μ is coefficient of friction (average tyre and road is 0.0055)
F_N is normal force
g is gravity acceleration
f_D is force of drag

ρ is mass density of the fluid (1.184 kg/m^3)

A is reference area of car body.

C_d is drag coefficient

v is velocity of the car

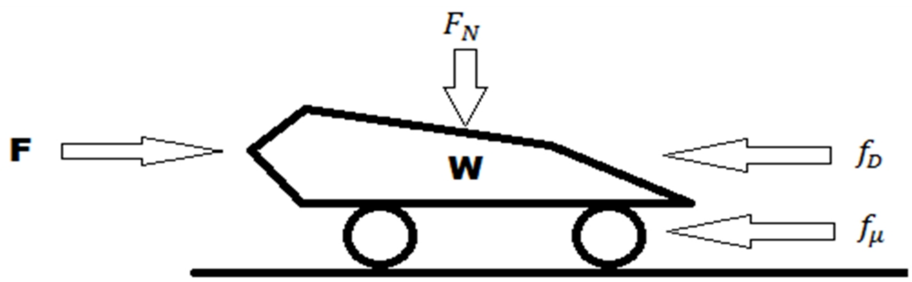

Figure 3.6: Example Schematic Car Diagram

Car specifications:

Maximum Car Weight	= 14.515 kg
Maximum Driver Weight	= 60 kg
Reference area of car body, A	= 5.6 m^2
Drag coefficient, C_d	= 1.1

The acceleration of the car is given by the equation below:

$$v = v_0 + at \qquad (3.5)$$

Where: v_0 is initial velocity of the car

a is acceleration of the car

t is time taken

v is velocity of the car

Target for the car:

The car need to speeding at the velocity 25 km/h (6.9444 m/s) in 10 second with the maximum mass of the car and driver is 74.52 kg.

The car acceleration is:

$$v = v_0 + at$$

$$6.944 = 0 + a(10)$$

$$a = \frac{6.944}{10}$$

$$a = 0.6944\, m/s^2$$

The force to move the car:

$$\sum F = m.a$$

$$F - f_\mu - f_D = m.a$$

$$F = f_\mu + f_D + m.a$$

$$F = F_N\mu + \frac{1}{2}\rho A C_d v^2 + m.a$$

$$= [(74.52 \times 9.81)(0.00375 \times 2)]$$

$$+ \left[\frac{1}{2}(1.184)(0.51096)(1.1)(6.944)^2\right] + [74.52 \times 0.3704]$$

$$= 49.13\, N$$

The torque that car needed is given by the equation below:

$$T = F.r \qquad (3.6)$$

Where: T is torque of the car

F is Force to move the car

r is radius of rear wheel

The power that car needed is given by the equation below:

$$P = F.v \qquad (3.7)$$

Where: P is power of the car
F is Force to move the car
v is velocity of the car

The torque required to move the car is:

$T = F.r$
$= 49.13 \times 0.2795$
$= 20.73\ N.m$

The power to move the car is:

$P = F.v$
$= 49.13 \times 6.9444$
$= 0.341\ KW$

The car also goes through on the sloping road, shown in Figure 3.7. That has a sloping angle of 10°. The initial velocity of the car before going through on the sloping road is 40 km/h (11.1111 m/s) and the car will be assumed to speeding at the velocity 20 km/h (5.5556 m/s) in 10 second to finish on the sloping road.

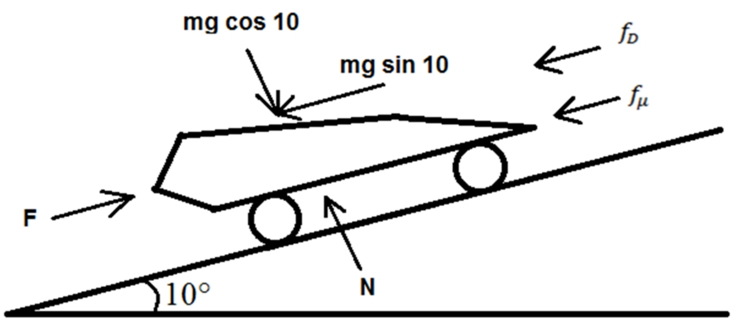

Figure 3.7: Example of Inclined car.

The car acceleration on the sloping road is:

$$v = v_0 + at$$

$$2.7778 = 6.9444 + a(10)$$

$$a = \frac{2.7778 - 6.9444}{10}$$

$$a = -0.4166\ m/s^2$$

The force to move the car on the sloping road is:

$$\sum F = m.a$$

$$F - f_\mu - f_D - mg\sin\theta = m.a$$

$$F = f_\mu + f_D + mg\sin\theta + m.a$$

$$F = F_N\mu + \frac{1}{2}\rho A C_d v^2 + mg\sin\theta + m.a$$

$$F = (mg\cos\theta)\mu + \frac{1}{2}\rho A C_d v^2 + mg\sin\theta + m.a$$

$$= [(74.52 \times 9.81\cos 10°)(0.00375 \times 2)]$$

$$+ \left[\frac{1}{2}(1.184)(0.51097)(1.1)(5.5556)^2\right] + [74.52 \times 9.81\sin 10°]$$

$$+ [74.52 \times (-0.4166)]$$

$$= 100.457\ N$$

The torque required to move the car is on the sloping road is:

$$T = F.r$$

$$= 100.457 \times 0.2795$$

$$= 28.97\ N.m$$

The power to move the car is on the sloping road is:

$$P = F.v$$

$$= 100.457 \times 2.7778$$

$$= 0.279W$$

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter aim to explain result about conceptual study on fuel cell that use in wheelbarrow. This result will explain in detail about system that propose to use in wheelbarrow using fuel cell, lithium battery, electric motor, fuel cell stack, and hydrogen generator. Detail explanation will show in this chapter.

4.2 LITHIUM BATTERY

Lithium battery use to supply electric to the system. Before motor get electric from the fuel cell, lithium battery supply electric to the motor. Lithium is the lightest metal and has greatest electrochemical potential and provides the largest energy density for weight.

Choices of lithium battery for this project because high energy density, compare to cadmium battery lithium battery more energy density. This system need battery can operate longer between charges while still consuming more power. Other reason for choices lithium battery is self-discharge of this battery is lower compare to other rechargeable battery such as Ni-cad and NiMH.

Besides that low maintenance cost the major why lithium battery was choosing for this project. Lithium batteries do not require and maintenance to ensure their performance compare the other type of battery. For example Ni-Cad cells required a periodic discharge to ensure that they did not exhibit the memory effect. Lithium battery has many variety types that suitable to use in the application that needed.

Battery use for this project see Figure 4.1, this battery with size (150 x 65x95) mm. Small size of battery is important because space to put the battery in wheelbarrow is small. Beside that chosen of this battery is lower cost and can be rechargeable. Voltage suggest for this system is 8 v, but lithium battery supply 12 v, that is more than enough to rotate the motor.

Figure 4.1: Lithium battery proposes on this project

Source: J.J Hwang (2004)

4.3 ELECTRIC MOTOR

Electric motors operate through the interaction between an electric motor magnetic field and winding currents to generate force within the motor. This system need to use motor for rotate wheelbarrow wheel. Inside the motor contain brushes commutator, motor coil, coil and magnets for the stator.

Selection of motor should be correct to give maximum power to wheelbarrow and prevent energy losses. Power from motor that need to this system about 0.082 kw until 0.22 kW, that was get from calculation. Detail of calculation has shown below. Amount of electric need to rotate the motor is 8 v.

The second Newton's Law equation:

$$F = m.a \qquad 3.1)$$

Where: F is Force to move the car

m is mass of wheelbarrow.

a is acceleration of the wheelbarrow

The force that acting at the car is friction force by tire and road, normal force and drag force can be calculated using the equation below:

$$f_{\mu} = F_N.\mu \qquad (3.2)$$

$$F_N = mg \qquad (3.3)$$

$$f_D = \frac{1}{2}\rho A C_d v^2 \qquad (3.4)$$

Where: is friction force by tire and road?

μ is coefficient of friction (average tire and road is 0.0055)

F_N is normal force

g is gravity acceleration

f_D is the force of drag

ρ is the mass density of the fluid (1.184 kg/m^3)

A is the reference area of wheelbarrow body

C_d is the drag coefficient

v is velocity of the wheelbarrow

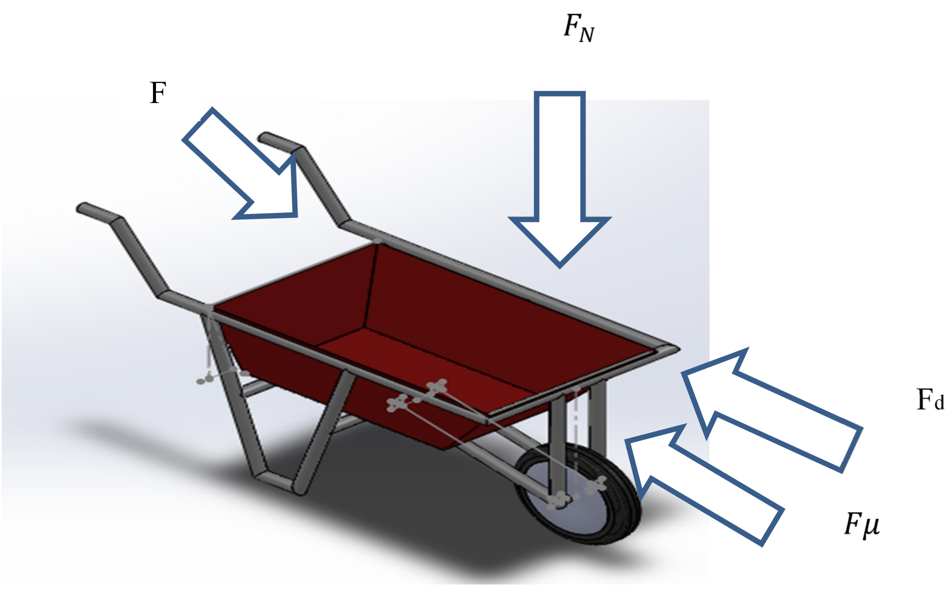

Figure 4.2: Force that acting on wheelbarrow

Wheelbarrow specifications:

Maximum Wheelbarrow Load	= 70 kg
Maximum Wheelbarrow Weight	= 10kg
Reference area of Wheelbarrow body, A	= 50.3m^2
Drag coefficient C_d	= 1

The acceleration for the wheelbarrow is given by the equation below

$$v = v_0 + at \qquad (3.5)$$

Where: v_0 is initial velocity of the wheelbarrow

a is acceleration of the wheelbarrow

t is time taken

v is velocity of the wheelbarrow

Target for wheelbarrow:

The wheelbarrow need to speeding at the velocity 10 km/h (2.78 m/s) in 10 second with the maximum mass of the wheelbarrow and weight is 80.00 kg.

The wheelbarrow acceleration is:

v=v_0+at

2.78=0+a(10)

$$a = \frac{2.78}{10}$$

$$a = 0.28\, m/s^2$$

The force to move the wheelbarrow:

$$\sum F = m.a$$

$$F - f_\mu - f_D = m.a$$

$$F = f_\mu + f_D + m.a$$

$$F = F_N\mu + \frac{1}{2}\rho A C_d v^2 + m.a$$

$$F = [(80 \times 9.81)(0.00375 \times 2)] + \left[\frac{1}{2}(1.184)(0.3)(1)(2.8)^2\right] + [80 \times 0.28]$$

$$= 49.13\, N$$

The torque that wheelbarrow needed is given by the equation below:

$$T = F.r \qquad (3.6)$$

Where: T is torque of the wheelbarrow

F is Force to move the wheelbarrow

r is radius of rear wheel

The power that wheelbarrow needed is given by the equation below:

$$P = F.v \qquad (3.7)$$

Where: P is power of the car

F is Force to move the wheelbarrow

v is velocity of the wheelbarrow

The torque required to move the wheelbarrow is:

$T = F.r$

$= 29.67 \times 0.076$

$= 2.26\ N.m$

The power to move the wheelbarrow is:

$P = F.v$

$= 2.78 \times 29.676$

$= 0.082\ KW$

Minimum power get from calculation for wheelbarrow which maximum load 70kg during straight line condition Figure 4.2 is 0.082 *KW,* maximum load cannot exceed the limit, because if exceed the limit performance of wheelbarrow will decrease, and motor performance also increase. Maximum torque and force during straight line condition is 2.26 $N.m$ and 49.13 N.

The wheelbarrow also goes through on the sloping condition Figure 4.3 that has a sloping angle of 10°. The initial velocity of the wheelbarrow before go through on the sloping condition is 15 km/h (5.555 m/s) and the wheelbarrow will be assume to speeding at the velocity 5 km/h (1.39 m/s) in 10 second to finish on the sloping road.

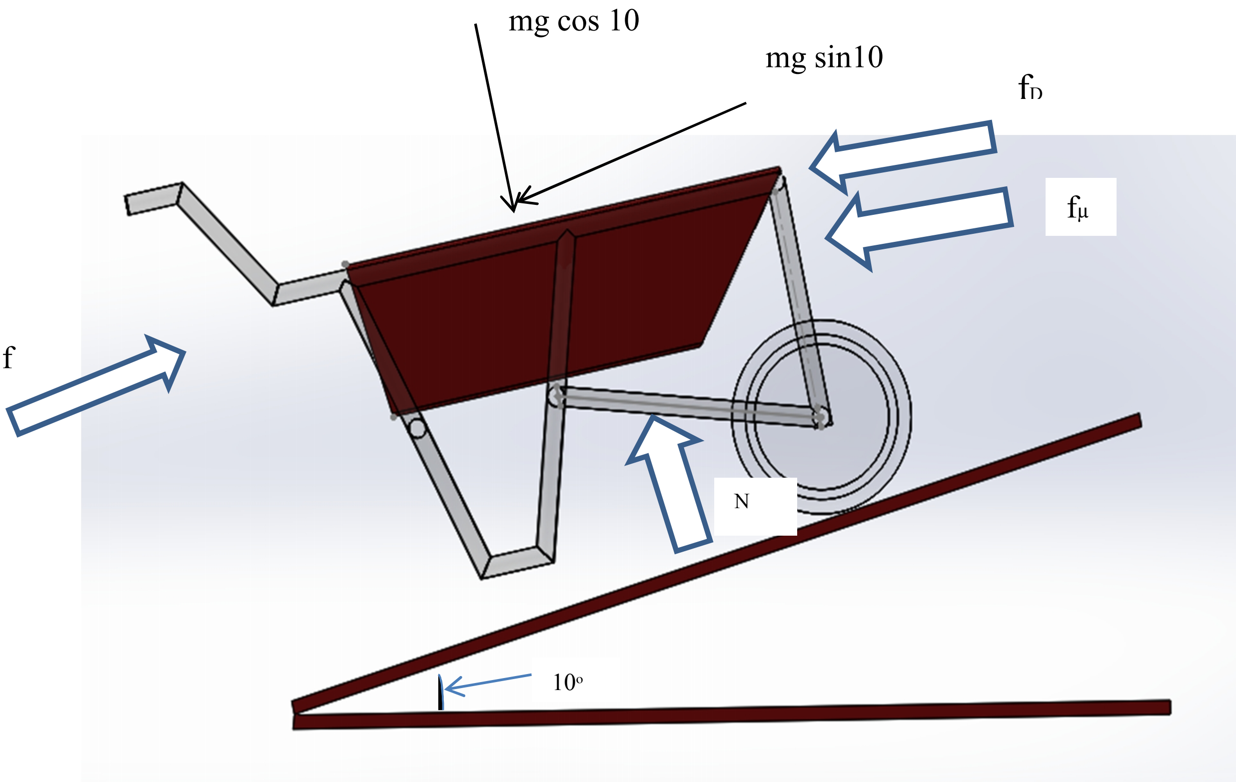

Figure 4.3: Force acting on wheelbarrow in inclined condition

The wheelbarrow acceleration on the sloping condition is:

$$v = v_0 + at$$

$$1.39 = 2.78 + a(10)$$

$$a = \frac{1.39 - 2.78}{10}$$

$$a = -0.139\, m/s^2$$

The force to move the wheelbarrow on the sloping condition is:

$$\sum F = m.a$$

$$F - f_\mu - f_D - mg\sin\theta = m.a$$

$$F = f_\mu + f_D + mg\sin\theta + m.a$$

$$F = F_N\mu + \frac{1}{2}\rho A C_d v^2 + mg\sin\theta + m.a$$

$$F = (mg\cos\theta)\mu + \frac{1}{2}\rho A C_d v^2 + mg\sin\theta + m.a$$

$$= [(80 \times 9.81\cos 10°)(0.00375 \times 2)] + \left[\frac{1}{2}(1.184)(0.3)(1)(2.8)^2\right] + [80 \times 9.81\sin 10°] + [80 \times (-0.139)]$$

$$= 79.42\ N$$

The torque required to move the wheelbarrow is on the sloping road is:

$$T = F.r$$

$$= 79.42 \times 0.076$$

$$= 6.04\ N.m$$

The power to move the car is on the sloping road is:

$$P = F.v$$

$$= 79.42 \times 2.78$$

$$= 0.22\ kW$$

The maximum of wheelbarrow power during inclined 10° angle, and maximum load 80kg that get from calculation is 0.22 kW, the maximum torque is 6.04 $N.m$, and the maximum force is 79.42 N.

Chosen of electric motor power is around 0.082 kW until 0.22 kW. The reason of specify the motor power is to reduce the losses of power and electric use in the motor in order to get a high performance in 80 kg weight at fix velocity.

4.4 FUEL CELL STACK

Fuel cell stack is the box that covering repeating element in fuel cell. Individual cells are stacked to achieve a higher voltage and power. This assembly is called a fuel cell stack. Repeating element in fuel cell stack contain cathode, electrolyte matrix, and anode. This element call typical unit cell. Figure 4.4 shown the element contain in fuel cell stack.

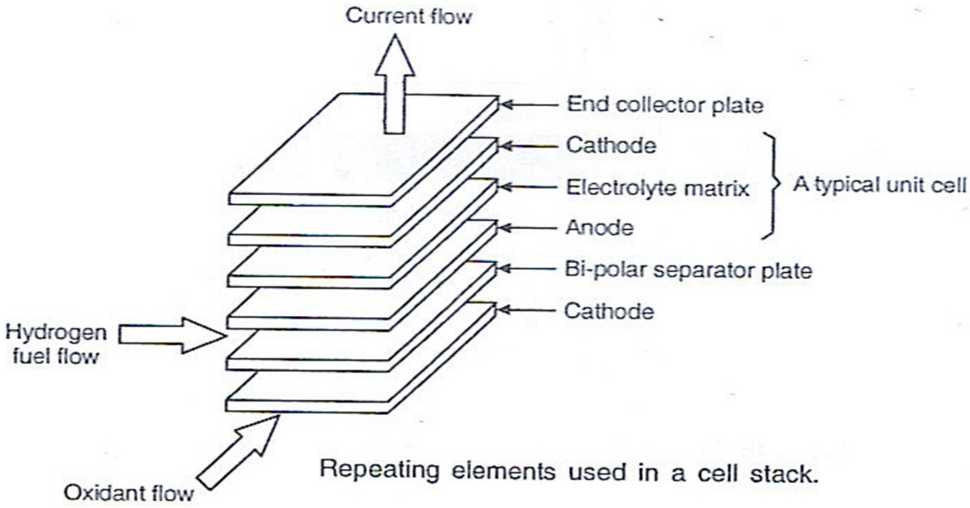

Figure 4.4: Fuel Cell Stack.

Source: Carrette J(2001)

Fuel cell stack arrangement in the real fuel cell has shown in Figure 4.5 below, the arrangement of fuel cell contain the end plate, bipolar plate, cooling plate, seal and Membrane Electrode Assemblies (MEA). End plate acts as a support for other plate in fuel cell. Bipolar plate in fuel cell stack act as a separator plates in a stack are bipolar where one side serves as the anode to one cell, and the other side serves as the cathode to the adjacent cell. Other job a bipolar plate is ensures gas in and out properly flow on the surface.

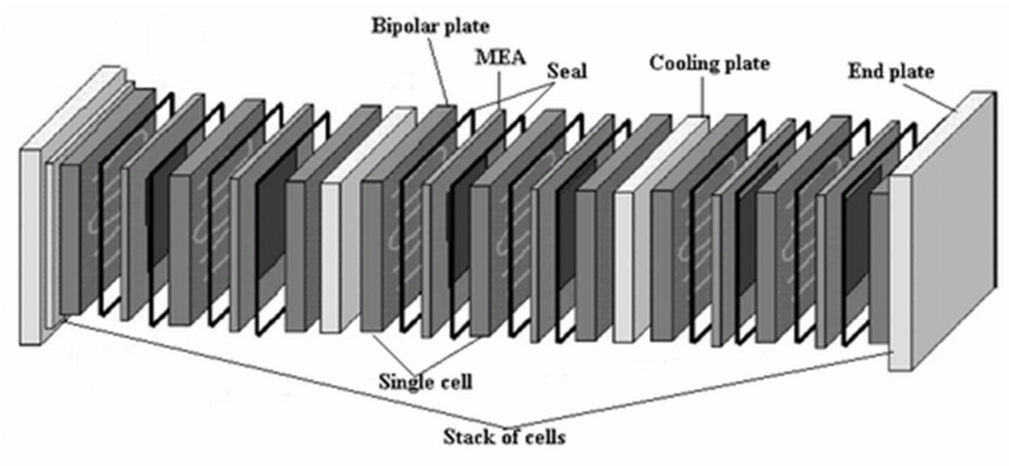

Figure 4.5: Fuel cell stack exploded view

Source: Kakati B.K (2008).

MEA in fuel cell stack separate the bipolar plate to make sure the electrolysis process properly done, in fuel cell stack. Seal was put between MEA and bipolar plate to prevent leakage of electrolyte, electrolyte leakage must prevent because electrolyte use to make sure fuel cell running correctly.

Commonly fuel cell stack effect the performance of fuel cell, arrangement component in fuel cell must be arrange properly to make sure fuel cell will running properly and get electricity as needed.

4.5 DESIGN OF THE CONTROL SYSTEM

Control system has been proposed to this project to control the amount of electric that enter the motor. Figure 4.6 show the parameter that contain in the system that can be used to powered wheelbarrow. The parameters contain filter, air pumps, pressure sensor, cooling fan, air exhaust, fuel cell stack, hydrogen storage tank, solenoid valve, and microcontroller.

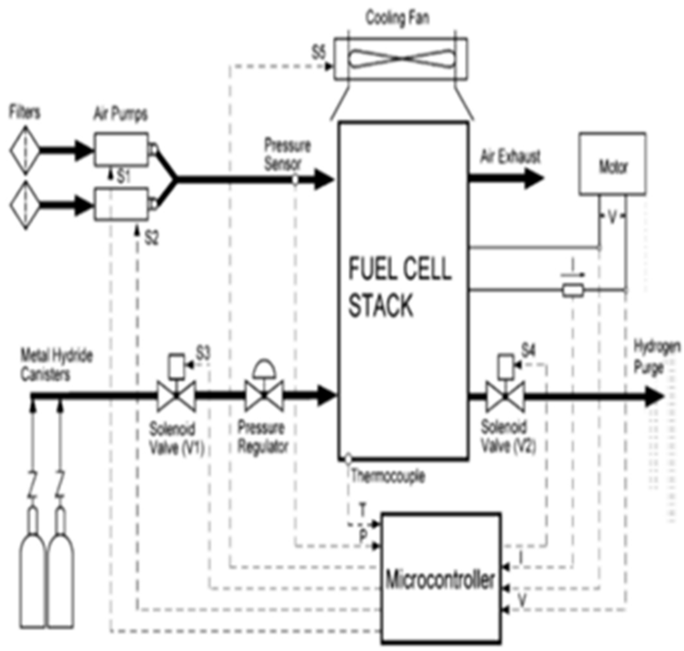

Figure 4.6: Control System

Source: J.J Hwang (2004)

Every parameters in the system has their own function, detail about function of the parameters in the system will be discuss. First is the filter, filter use to filter the oxygen that get from to surrounding to make sure the oxygen clean from dust. Second are the air pumps, air pump function to pumps air to the fuel cell stack, through pressure sensor. Pressure sensor function is to detect amount of air that enter the fuel cell.

Microcontroller function is to controller the valve open or close, for make sure amount of air that enter the fuel cell stack is enough. Function of cooling fan is to cooling down the temperature of fuel cell stack. Heat and water as a waste product, for this system, so using of cooling fan to cooling down the system is suitable.

Beside that function of fuel cell stack is to located anode, cathode, fuel cell membrane and seal. Function of motor in the system is to rotated the wheel and make sure the wheelbarrow move. Hydrogen canister in this system was change to the hydrogen generator, function of hydrogen generator is to supply hydrogen to the fuel cell stack. Solenoid valve and pressure regulator is to control the amount of air that enters the fuel cell stack.

The system function work start with oxygen enters the filter through the air pumps to the fuel cell stack. Pressure sensor sent the information the amount of air that enter to the fuel cell stack, after that microcontroller open the solenoid valve of hydrogen to allow the hydrogen enter the system through the pressure regulator, microcontroller was fix the amount of hydrogen that can enter the fuel cell stack. After reaction electric was sent to the microcontroller after that microcontroller sent the electric to the motor, waste product of the system such as water and heat was taking out to system.

After several time of reaction microcontroller sent the information for cooling fan to rotate, cooling fan rotate to cool down the fuel cell stack, and make sure the system running properly.

4.6 HYDROGEN GENERATOR

This subtopic describe function of hydrogen generator is to supply hydrogen to fuel cell. Fuel cell needs hydrogen to react with hydrogen for produce electric. Hydrogen generator has been fabricated.

Main reason of fabrication hydrogen generator in fuel cell is Malaysia did not have many refill center of hydrogen. If user use hydrogen tank as a hydrogen source, user will difficult to find refill center if hydrogen in the tank was finish. Other reason is hydrogen generator is light, the weight around 1kg this weight suitable to install in the system.

There are several other reason on fabricating hydrogen system is save for consumer, inside hydrogen generator did not has any dangerous material that can dangerous for consumer. Hydrogen generator also cheap to fabricate, the total cost around RM 34.90 Table 4.1 shown the cost analysis for fabricate hydrogen generator.

Table 4.1: Cost analysis for fabricate hydrogen generator.

Component	Dimension (mm)	Unit	Cost (RM)
Steel plate	100x100	23	
Rod	D8x179	2	
Wire	D8 x 259	2	
Water Filter	30 x D18	1	29.90
Bolt and Nut	M8	4	
Hose	D5 x 1000	1	3.00
Water Battery		1	2.00
		Total	34.90

Process fabricated hydrogen generator start with sketching, after finish the sketching, design of hydrogen generator was sketch using solidworks, Figure 4.7 shown the hydrogen generator sketching using solidworks software, and Table 4.2 shown the dimension of hydrogen generator. Inside the hydrogen generator contains plate, function of the plate is to do electrolysis process to produce hydrogen that cab be supply to the system has shown in Figure 4.8.

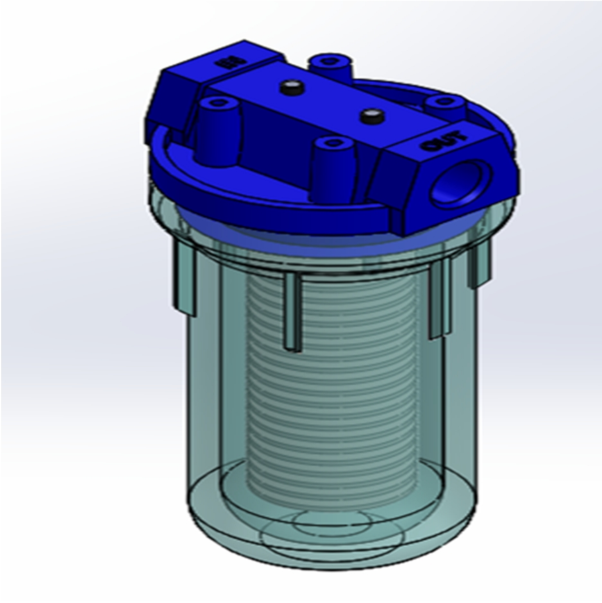

Figure 4.7: Solidworks sketching of hydrogen generator.

Table 4.2: Dimension of hydrogen generator

Item	Length (mm)
Diameter	180
Height	300

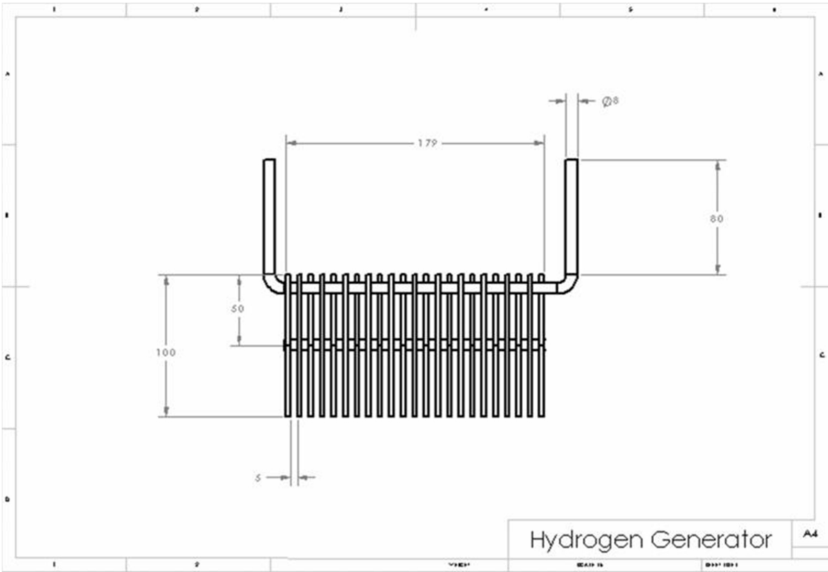

Figure 4.8: Assemble sketching plate inside the hydrogen generator

Some calculation has been made to know amount of mass flow rate for hydrogen that need to get for the system to produce 8 v of electric. Before get the mass flow rate of hydrogen, no of molar mass hydrogen should be fine first, formula of the calculation has shown below

Data

1-One equivalence of electrons is 1 g mol of electrons or 6.022 x1023 electrons (Av No's)

2 -This quantity of electrons has the charge of 96,487 coulombs (C) (Faraday's constant)

3- Thus, the charge of a single electron is 1.602 x10 -19 C

4- One (1) ampere of current is defined as 1 C/sec.

$$n_{H_2} = (8A)\left(\frac{1coulumb/sec}{1A}\right)\left(\frac{1equivalence\ e^-}{96{,}487\ coulumb}\right)\left(\frac{1\ g\ mol\ H_2}{2\ equiv.of\ e^-}\right)\left(\frac{3600\ sec}{1hr}\right) \quad (4.1)$$

$$= 0.149\ \frac{g\ mol}{hr.A}H_2$$

$$m_{H_2} = \left(0.149 \frac{g\,mol}{hr.A} H_2\right)\left(\frac{2.0158\,g}{1\,g\,mol\,H_2}\right)\left(\frac{1\,kg}{100\,g}\right) \quad (4.2)$$

$$= 3.003\,x\,10^{-4}\,\frac{kg\,H_2}{hr.A}$$

From the calculation, the number of molar for hydrogen is 0.149 $\frac{g\,mol}{hr.A} H_2$ and the number of molar mass of hydrogen is 0.003 kg H2/hr. kA. To rotated electric motor using fuel cell, for 80 kg load molar mass of hydrogen need is $3.003\,x\,10^{-4}\,\frac{kg\,H_2}{hr.A}$

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter concludes all that has been done and achieved in this conceptual study, and some recommendations on how to improve this finding of conceptual study in future research to get a better result.

5.2 CONCLUSION

Overall of this project is achieved to study the conceptual of fuel cell that can be powered wheelbarrow. The design of the system that can be used to wheelbarrow was proposed, the design can be used for fuel cell for power wheelbarrow. Fuel cell stacks use and arrangement, electric motor chosen, hydrogen generator analysis cost has been defined, and chosen of battery has been done in this conceptual study. All parts that need to be considered for building fuel cell that can power wheelbarrow has been done. This simple explanation about parameters was found from conceptual study, the firstly power of electric motor that has been calculated. Power of the electric motor is 0.082kW until 0.22 kW, which is powerful enough to move load not exceed 80kg with velocity 2.78 m/s. The second parameter that needs to consider is hydrogen generator analysis cost. The cost around RM 39.90, this cost is cheap compare that the cost of refill the hydrogen at the hydrogen refill center. The third parameter is the battery used for this project is lithium ion battery. This battery has some advantage such as light, cheap, and did not need maintenance after use in several times.

5.3 RECOMMENDATION

Recommendations for this conceptual study is before fabricate the fuel cell stack, bipolar plate that wants to use should be analysis first before produce the bipolar plate. Bipolar plate flow is important to hydrogen and oxygen to flow and react. The performance of the fuel also depends on the bipolar plate pattern flow. Another recommendation is to create simple systems that want to use for this project. The last recommendation is about hydrogen generator. Before fabricating the hydrogen generator, the amount of hydrogen need should be calculated first, to make sure the system to have enough hydrogen supply.

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