FEASIBILITY STUDY OF HHO CELL FOR 150CC MOTORCYCLE SI ENGINE

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A report submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering with Honours

Faculty of Mechanical Engineering

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DECLARATION

I declare that this project report entitled “Feasibility Study of HHO Cell for 150cc Motorcycle SI Engine” is the result of my own research except as cited in the references.

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SUPERVISOR DECLARATION

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree in Bachelor of Mechanical Engineering with Honours

Signature: ……………………………….................................

Supervisor: PROF. TS. DR. NOREFFENDY BIN TAMALDIN

Date: ……………………………………………………………

DEDICATION

In the name of Allah, the Most Gracious and the Most Merciful

I dedicate this work to:

My parents,

Kelvin Sembai Abdullah and Shafiah Binti Mohd Hatim

My siblings,

Supervisor who always give support and encouragement,

Professor Ts. Dr. Noreffendy Bin Tamaldin

ABSTRACT

Internal combustion engine (ICE) is an old technology and has a long history of evolution. The need for another power source in order to maintain its sustainability for the future is being much highlighted in today's scientific community. Amongst the different alternative fuels, HHO gas is found to be the most viable solution in regards of its generation and storage as it is considered renewable, recyclable, and non-polluting fuel. The use of HHO gas in gasoline engines is relatively new. Any improper addition or modification to the engine may cause performance deterioration instead of enhancement. In this study, various HHO plates with different surface roughness are fabricated for HHO gas production analysis to match the specified engine. Further test will be done by tuning the input voltage supply and weight of catalyst used. The optimum flowrate of HHO gas will then be commissioned into the air intake manifold of the engine for the analysis of performance and emission. The various surface roughness of the plates are obtained by grinding and polishing the surface to mirror-like surface and categorised to non-polished, one-sided polished, and fully polished. The surface roughness of the plates are inspected with metallographic microscope and measured with a roughness tester. The analysis of HHO gas production with the three types of plates are done with a flow meter while the specified engine is set up with a dynamometer for analysis of performance and emission. The manipulated variables are the voltage input and weight of catalyst used to find the optimum setting for the specified engine. By commissioning the HHO gas into the air intake manifold, the analysis of performance and emission are done to evaluate its effectiveness. In the findings, the rougher surface of the plates produced the most HHO gas under the same condition. The performance of the engine only improved by a small margin but the emission improved vastly with the addition of HHO gas.

ABSTRAK

Enjin pembakaran dalaman (ICE) adalah teknologi lama dan mempunyai sejarah evolusi yang panjang. Topik untuk sumber kuasa yang lain untuk mengekalkan kelestariannya demi masa depan semakin hangat dalam komuniti saintifik hari ini. Di antara pelbagai bahan bakar alternatif, gas HHO didapati penyelesaian yang paling berdaya maju dalam hal penjanaan dan simpanannya kerana ia dianggap sebagai bahan bakar yang boleh diperbaharui, kitar semula, dan tidak mencemarkan. Penggunaan gas HHO dalam enjin petrol agak baru. Sebarang penambahan atau pengubahsuaian yang tidak betul kepada enjin boleh menyebabkan kemerosotan prestasi dan bukan peningkatan. Dalam kajian ini, pelbagai plat HHO dengan kekasaran permukaan yang berbeza direka untuk analisis pengeluaran gas HHO untuk menyesuaikan dengan enjin yang ditentukan. Ujian selanjutnya akan dilakukan dengan mempelbagai bekalan voltan dan berat katalis yang digunakan. Kadar aliran gas HHO yang optimum kemudiannya akan dimasukkan ke manifold pengambilan udara enjin untuk analisis prestasi dan pelepasan. Pelbagai kekasaran permukaan plat diperolehi dengan mengisar dan menggilap permukaan sehingga merupai permukaan seperti cermin dan dikategorikan kepada tidak digilap, satu sisi yang digilap, dan digilap sepenuhnya. Kekasaran permukaan plat diperiksa dengan mikroskop metalografi dan diuji dengan penguji kekasaran. Analisis pengeluaran gas HHO dengan tiga jenis plat dilakukan dengan meter aliran manakala enjin yang ditetapkan didirikan dengan dinamometer untuk analisis prestasi dan pelepasan. Pembolehubah dimanipulasi adalah input voltan dan berat pemangkin yang digunakan untuk mencari tetapan optimum untuk enjin yang ditentukan. Dengan memasukkkan gas HHO ke dalam manifold masuk udara, analisis prestasi dan pelepasan dilakukan untuk menilai keberkesanannya. Dalam penemuan, permukaan yang lebih keras plat menghasilkan gas HHO yang paling dalam keadaan yang sama. Prestasi enjin hanya meningkat dengan margin yang kecil tetapi pelepasan bertambah dengan penambahan gas HHO.

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LIST OF ABBREVIATIONS

KOH	Potassium Hydroxide
H_2O	Water
TCI	Transistor Controlled Ignition
SOHC	Single Overhead Camshaft
IC	Internal Combustion
H_2	Hydrogen gas
CO_2	Carbon Dioxide
HC	Hydrocarbon
CO	Carbon Monoxide
HHO	Oxyhydrogen
DC	Direct Current
SI	Spark ignition
PVC	Polyvinyl Chloride
HDPE	High Density Polyethylene
NaOH	Sodium Hydroxide
NaCl	Sodium Chloride
TDC	Top Dead Centre

LIST OF SYMBOLS

V	=	Voltage
I	=	Ampere
R	=	Ohm
cc	=	Cubic centimeter
Nm	=	Newton meter
Ah	=	Ampere hour
kW	=	Kilowatt
hp	=	Horsepower
A	=	Ampere
ppm	=	Parts per million

CHAPTER 1

INTRODUCTION

1.1 Background

One of the major problems the scientific community facing today is global warming. With many theories suggested that the increase of exhaust gases concentration in the atmosphere as one of the major contributors of the global warming (Ishida et. al., 2003). Besides, the ever increasing use of the conventional fossil fuels in the transportation sector and the associated environmental impacts have become the major concern worldwide. The world energy consumption in the transportation sector, in particular, increases by an average of 1.1 percent per year (EIA, 2013). The exhaust pollutants from the internal combustion (IC) engines also contributes greatly to the total environmental pollution worldwide. Combining all the issues of the fluctuation of fossil fuels' price, an increase in the concerns environmental issues and energy security, plus the stricter rules and regulations on engine or vehicle emissions, this have led researchers to put more efforts and interest towards alternative fuels and advanced vehicle technologies.

Among the different alternative fuels, researchers have used biogas, syngas, producer gas either solely or with H_2 blends successfully in gasoline engines. H_2 gas is a carbonless fuel whose combustion does not generate emissions such as HC, CO and CO_2, but from the commercial point of views there are concerns in regards to the viable solutions for both the generation and storage of H_2. The use of hydroxy gas (HHO gas) in gasoline engines is relatively new. It can be considered as a renewable, recyclable and non-polluting fuel as it does not contain carbon in its molecule. Hydroxy gas is also known as HHO, Brown's gas, Water gas and Green gas. HHO gas stands for Hydrogen-Hydrogen-Oxygen gas with the mixture of H_2 and O_2 in a ratio 2:1 by volume. The HHO gas is the product of water electrolysis, which is invented since March, 1978 by Yull Brown (Yull, 1978). Hence, electrolytic gas often called as "Brown's gas" or Hydrogen Rich Gas (HRG).

Water electrolysis is a technique that utilizes a direct current (DC) to split water into protons, electrons, and gaseous oxygen at the anode (positive electrode) and hydrogen at the cathode (negative electrode) in the electrolyzer. The basic idea of electrolysis in HHO production process is to separate the hydrogen and oxygen atoms in a water molecule. The product of the process, which is the HHO gas will be mixed with air before being fed into the combustion chamber. With the addition of HHO gas, (Ammar, 2010) indicated that the effect on the reduction of fuel consumption is as the same as if hydrogen had been used.

1.2 Problem Statement

The spark ignition (SI) engine is one of the three types of combustion engines in practice; Spark ignition engine, Diesel engine and Turbine engine. In these engines, the unburned fuel remains after the burning process. The unburned fuel leads to performance losses and air pollution which is one of the biggest challenges that researchers face in the automobile industry. The HHO cell is an efficient approach to increase engine performance as well as to reduce exhaust pollutants released to the air.

In this study, the focus is to find an efficient surface roughness of HHO plate for Yamaha 150cc SI engine. As the production of HHO gas will be mixed with air before entering the combustion chamber, the flowrate of HHO gas produced entering the engine air intake has to be analysed. Moreover, the mismatch of air-fuel ratio (AFR) will result in performance deterioration. This may also lead to potential problems that includes engine knocking, increase in fuel consumption and emission. Hence, not only the engine performance will be affected, but the engine life will also be reduced. Therefore, a proper study on the analysis, evaluation, design and fabrication of an efficient HHO plate's surface roughness will be able to increase the engine performance while reducing air pollution.

1.3 Objective

The objectives of this project are as follows:

1. To fabricate various HHO plate surface roughness for HHO gas production analysis to match the specified engine.
2. To analyse the flowrate of HHO gas produced with various voltage input and weight of catalyst.
3. To evaluate the engine performance and emission from the commissioning of HHO cell with the motorcycle SI engine.

1.4 Scope of Project

The scopes of this project are:

1. Fabrication of HHO plates with various surface roughness suitable for the specified engine.
2. Testing of Yamaha 150cc motorcycle SI engine for baseline analysis.
3. Tuning of input voltage supply from DC source and weight of catalyst for efficient HHO gas flowrate and improved combustion.

1.5 General Methodology

The actions that need to be carried out to achieve the objectives in this project are listed below.

1. Literature review

   Journals, articles, or any materials regarding the project will be reviewed.

2. Analysis

   Baseline testing and analysis will be performed with the Yamaha 150cc SI engine with dyno to understand the engine requirement for HHO cell integration.

3. Fabrication

   The design rule of the HHO cell plate will be fabricated to cater for Yamaha 150cc SI engine.

4. Evaluation

   Evaluation will be made on the comparison of engine performance and emission for Yamaha 150cc SI engine and optimization of HHO cell flowrate to match engine intake requirement for perfect combustion with and without HHO cell.

5. Report writing

   A report on this study will be written at the end of the project.

CHAPTER 2

LITERATURE REVIEW

This chapter will discuss about the literature review by referring to journals, books, articles and any material related to the feasibility study of HHO cell for 150cc Motorcycle Engine to obtain the data. HHO generators had been studied by many researchers before. The topics that will be discussed in this chapter are the working principles of HHO generator, types of HHO cell, catalysts used in HHO generator, cell design include electricity supply on HHO cell, cell plate and a summary of the cells being discussed.

2.1 HHO Generator

A HHO or Brown gas generator is a device that can convert water molecules into HHO molecules. The concept of HHO generator is a relatively new technology. It is often referred to as HHO gas or Brown gas generator due to its working principle of using the concept of electrolysis to split water (H_2O) into its base molecules of 2 hydrogen and 1 oxygen molecules with suitable electrodes and catalyst-added solution to enhance the process.

It is generally made up of three essential components – electrodes, solution, and electric current (Affan, 2016). It uses the electrodes connected to an electric current to pass through a solution to decompose the solution or a molten compound (Bhardwaj et. al., 2014). Through this process, an enriched mixture of hydrogen and oxygen or Oxy-Hydrogen bonded together molecularly and magnetically will be produced in the form of HHO or Brown gas (Akash, 2014).

A HHO or Brown gas generator works when electrode plates are dipped in water mixed with electrolyte or catalyst in it (Arvind et. al., 2014). A loop of electric current is generated when the electrode plates are connected to a DC power supply that provides the electric current. This continuous loop of electric current between the power supply, electrodes and the solution will decompose or dissociate the catalyst-added solution to produce HHO or Brown gas. The electrolyte or catalyst used to mix with the solution is potassium hydroxide (KOH). It is mostly mixed with 20 - 30 wt. % of the solution because of the optimal conductivity and require to use corrosion resistant stainless steel to withstand the chemical attack (Aaditya et. al., 2015). The increase in the amount or amplitude of electric current supplied can also increase the rate of HHO gas generation (Vino, 2012).

There are getting more studies that are being conducted to research on the design of an on-board hydrogen generation system. This can be done either from the regeneration of hydrogen from the vehicle's fuel supply or generating hydrogen from electrolysis of water (Nikhil and Deepak, 2015). The rate of HHO gas generation and the liberated volume of the gas directly depends on the concentration of electrolyte, amplitude of electric current and the area of contact between the electrodes and the solution (Kumar and Rao, 2013)

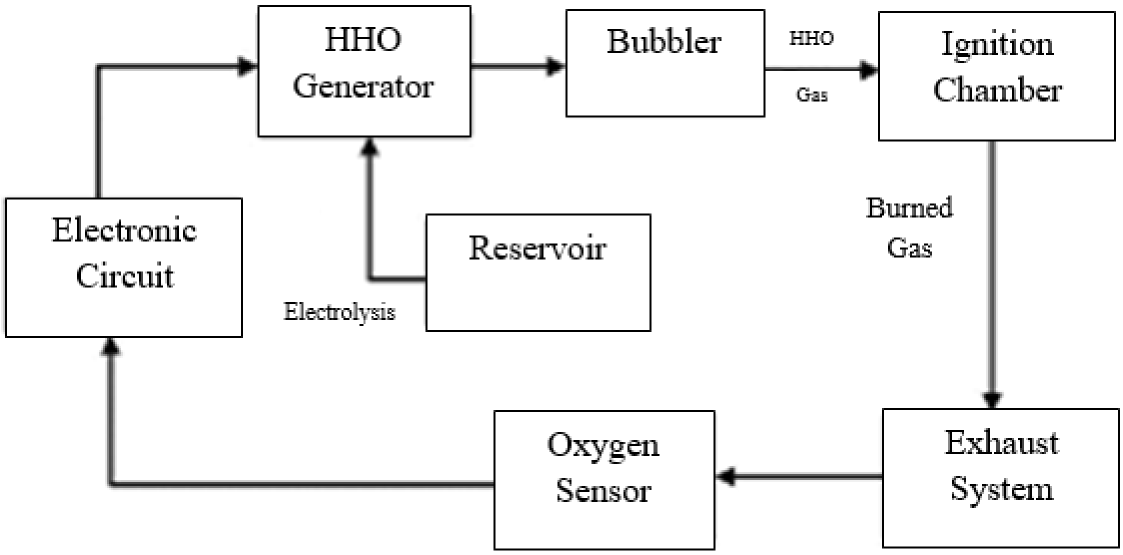


Figure 2.1: Block Schematic Diagram of HHO Generator Integration With IC Engine

2.1.1 HHO Separation Tank

After the HHO gas is produced in the HHO generator, the gas flows to the HHO separation tank. A HHO separation tank or Hydrogen Bubbler is a device that acts as a one-way valve to prevent explosive flashback or flow back of the generated HHO gas from moving back to the HHO generator. It performs this function by bubbling the HHO gas through a non-flammable liquid so that flashback from any source is arrested. From safety point of view, this device works as a vital component to prevent any unwanted events. From the separation tank, the HHO gas flows through the pipe to the air intake of the engine (Prithivirajan et. al., 2015).

The HHO separation tank is generally constructed from a PVC pipe that has a capacity of 3 litres depending on the size of the HHO generator. The HHO separation tank and its components are shown in Figure 2.1 used in the study (EL-Kassaby et.

al, 2015). It was made of 8.9 cm of PVC pipe (1) with a capacity of 2.2 L. The PVC end caps (2) were used to seal the top and bottom. To refill the tank with distilled water with dissolved catalyst, a 1.27 cm PVC ball valve (3) was used. Hoses would be connected to the water inlet (4) and HHO gas outlet from the cell. The distilled water with dissolved catalyst would be carried to the cell through outlet (5) before entering the HHO gas outlet (6) to the engine. It is also constructed with a Pressure gauge (7) with vacuum range of 0 – 1 bar and a spring loaded vacuum breaker.

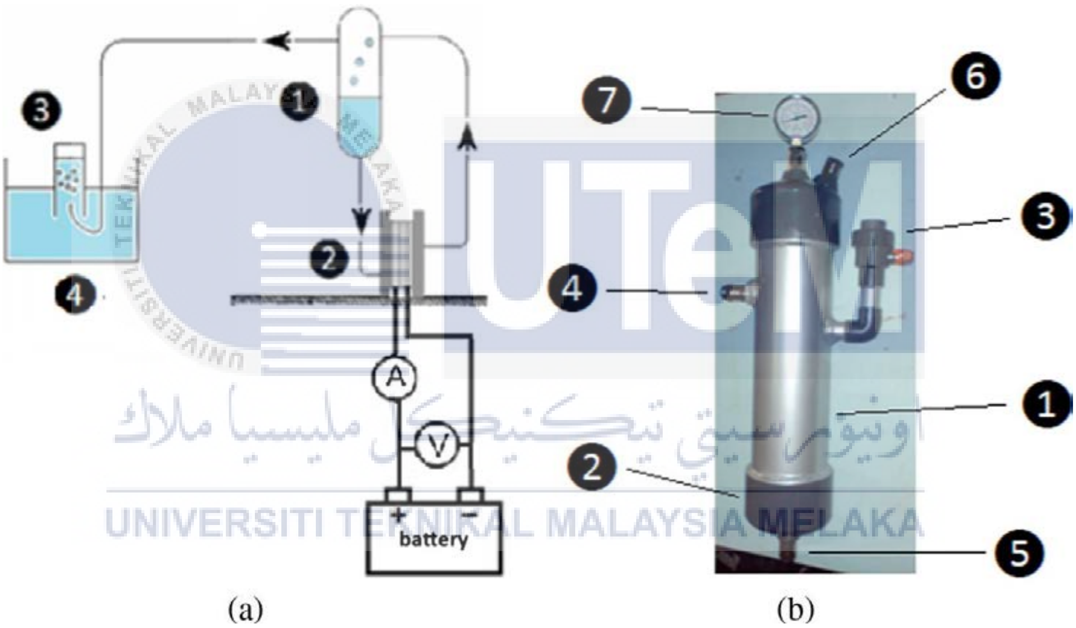


Figure 2.2 (a): Schematic diagram of the HHO gas generation system.

Figure 2.2 (b): HHO separation tank components.

2.1.2 Spacer

Spacer is a series of non-conductive plates usually made of High Density Polyethylene (HDPE) with 3mm thick. These non-conductive plates are placed in between the stainless steel electrode plates (SS316L). It acts to insulate the electrode plates from getting in contact with each other and functions as an electric current leakage prevention system. For a generator cell comprises of 6 electrode plates, it is usually arranged in a 2 by 3 plat formation.

2.1.3 Gasket

To prevent water and gas leakage from the HHO generator, gaskets are used that acts as the barrier between the HHO generator frame. The gaskets should be able to close tightly between the small gaps in order for it to prevent any water or gas leakage between HHO cell and the casing of the cell. The materials used are usually rubber type MBR with 2mm thick.

2.1.4 Cell Generator Cover

The cover is used to clamp together the stainless steel electrode plates with the spacers in between. It is usually constructed from acrylic material. The left and right sides of the plates will be mounted baud by welding to act as current conductor for the anode and cathode of the stainless steel electrodes.

2.1.5 Inlet and Outlet

The inlet and outlet are the parts where the movement of the generated HHO gas and electrolytic solution is being refilled. The inlet is used to fill the distilled water solution which has been mixed with the KOH electrolyte into the HHO cell. The outlet is used as an output source for the HHO gas to enter the separation tank.

2.2 HHO Cell

There are mainly two types of HHO cell readily available in the market – dry cells and wet cells. Through time and various researches being done, the concept of combining both dry cells and wet cells is being materialized. It is often referred to as hybrid cell. It works both ways while taking advantages of the pros of both cells. The electrode plates in all types of HHO cell are connected with a power source to decompose water molecules using electrolysis process to produce HHO gas. All types of HHO cell have a slightly different working principles but will produce the same HHO gas.

2.2.1 Dry Cell

A dry cell is generally comprised of sets of electrode plates, clamped together and separated by gaskets for each plate, with holes in between the plates (Lalnunthari and Hranghmingthanga, 2015). This allows the electrolytic solution to flow through the holes in between each plate. The dry cell is designed with gaskets separating the plates to eliminate edge currents inefficiencies. The disadvantage of this design is although it reduces the laminar flow, this causes the foaming of electrolytic solution which can destroy delicate aluminium parts of the engines if leakage occurs. Due to restrictive fluid dynamics and gas back-pressure, this causes poor heat transfer thus affecting the efficiencies of the system negatively.

The compact design of dry cell can complement modern engines in terms of an added fuel saving feature as well as it requires less maintenance (Egan et. al, 2013). Due to its rather small volumetric size of solution within the closed chamber, it requires only lesser current for each cell. Lesser volumetric size of solution also contributes to less corrosion from occurring on the anode plates due to the restricted volume of electrolyte solution per second.

Figure 2.3: Dry Cell HHO Generator Type (Bambang et. al., 2016)

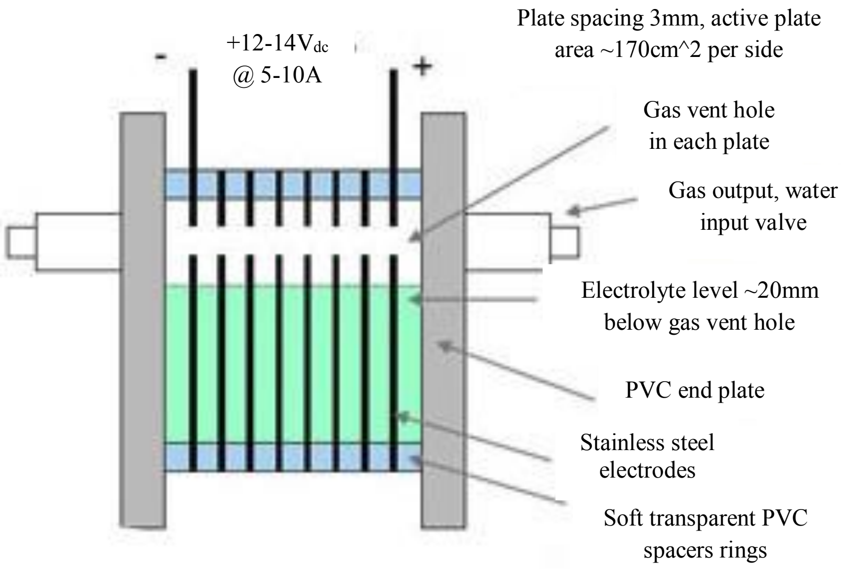


Figure 2.4: Dry Cell Assembly

2.2.2 Wet Cell

A wet cell is usually comprised of stacks of electrode plates immersed in a bath of electrolytic solution. This is the most common method of electrolysis and is most widely used in industry today. The wet cell designs have a good laminar flow which is good for hydrogen production because it is immersed in electrolytic solution.

The disadvantages of the wet cell are that it requires more electric current hence it generates more heat and can cause corrosion through the positive electrodes (Egan et. al., 2013). Electrical and magnetic eddies can occur due to exposure of the electrode plates that allows the jumping of electric current from edges to edges. This causes inefficiency and power loss due to energy leaps around the electrolytic solution instead of transferring in between the plates, where the majority of electrolysis takes place. In mobile applications, this is not suitable where both efficiency and portability are important.

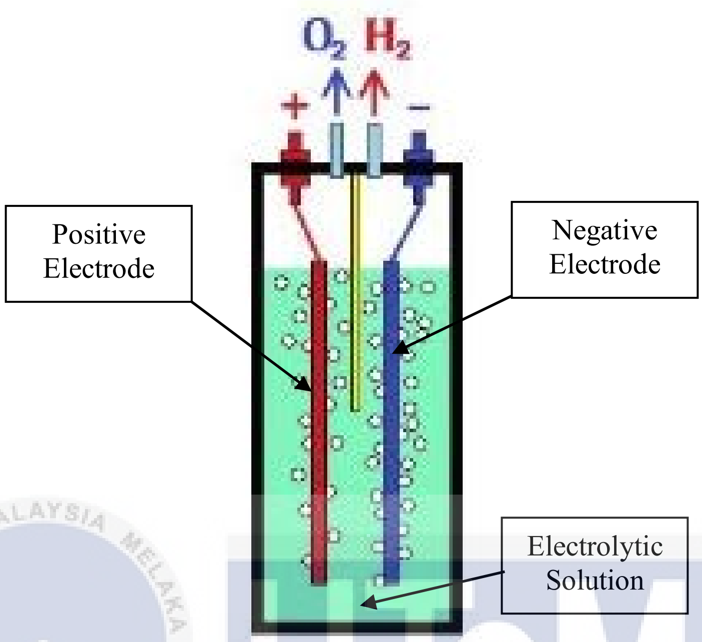


Figure 2.5: Wet Cell Assembly (De Silva et. al, 2015)

2.2.3 Hybrid Cell

Hybrid cell is a combination of two types of HHO cell that is dry cell and wet cell. The hybrid cell is generally a formation of the dry cell being placed in a chamber containing the electrolyte liquid as in the wet cell type. The wet cell and dry cell designs have both advantages and disadvantages by way of efficiencies and gas production but neither is perfected in its present form.

The hybrid cell takes advantage of the improved laminar flow of wet cells, while sealing off most exposed edges, greatly reducing the losses that would normally occur, while still maintaining comparable flow. It also completely encloses the plate edges reducing or eliminating any danger of sparks from shorting between the plates. It mimics the efficiencies of the dry cell, but additionally maintains the effective laminar flow rate of a wet cell to greatly reduce foaming and restricted gas flow, resulting in a more efficient system.

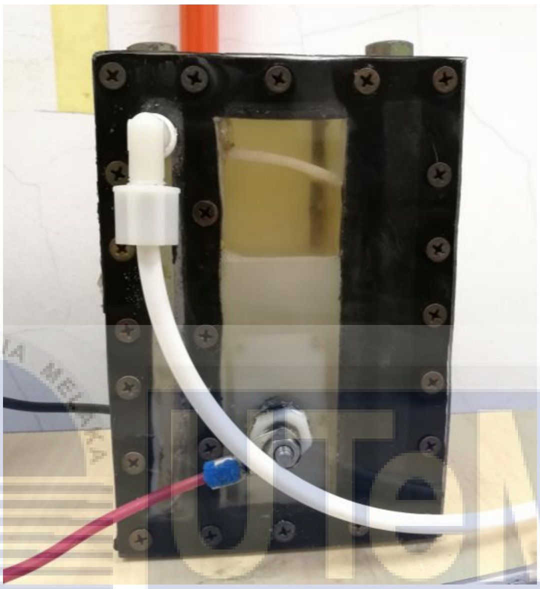


Figure 2.6: Hybrid Cell Assembly

2.3 Cell Design

2.3.1 Cell Plate

The electrode plate serves as electrical current conductor to the electrolytic water and the site for electrolysis. In electrolysis using DC current, the electrode is divided into two valves which are positive as anode and negative as cathode. The material and extent of the electrode used affects the HHO gas generated from the water electrolysis process so that the electrode material must be selected from good electrical conductivity materials with corrosion resistance. (Putha and Satish, 2015).

High corrosion resistance is considered as one of the major factors for electrode material due to its high corrosive working ambient (Thanga et. al., 2016). If other metals are used as the anode, there is a chance that the oxygen will react with the anode instead of being released as a gas (Tabazah, 2014). Stainless steel type SS 316F, 316L, 316N, 317, 329, and 304 have excellent corrosion resistance in various environments, therefore are suitable as electrode in the water electrolysis process to produce HHO gas (Refaey et. al., 2004). In this study, the 316L stainless steel was used as electrode due to its low carbon content.

In the industry, the electrode surface modification is made with the aim of making the bubble passing the surface easier. One of the proposed methods is mechanical polishing by 3 different classical sandpapers of P400, P2000, P4000 (seed size 35, 10, 5 mm) (Kjartansdóttir, 2013) (Lavorante, 2016). Through mechanical polishing, it was found that the rougher the surface of the plate, the higher the effective surface area. This will lead to higher electrical conductivity as the plates exhibit lower over potential (Zeng and Zhang, 2014).

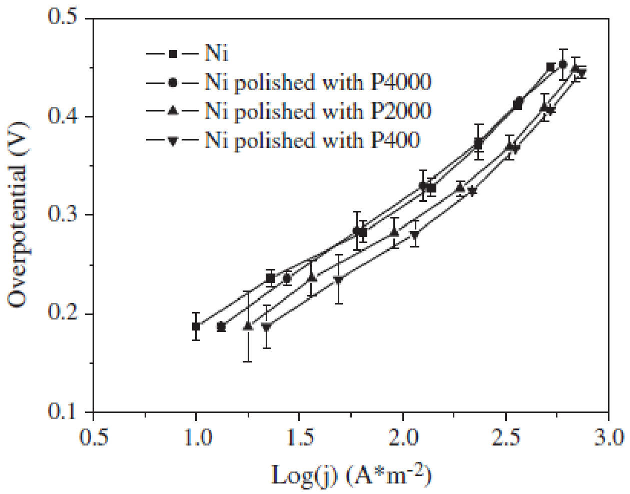


Figure 2.7: Tafel curves of HER illustrating the apparent activity of the Ni electrodes polished with different sandpapers (Zeng and Zhang, 2014)

2.3.2 Electrical Energy

As the process of producing HHO gas involves water electrolysis method, this method requires the electrical energy to complete the loop of continuous electric current to split the water molecules to its base molecules. Therefore, the magnitude of generator input electric voltage should be evaluated to find the best setting to suit the demands of the HHO generator. The electric energy in the forms of input electric voltage is necessarily to provide the energy and movement for electrons during the electrolysis process.

Ohm's Law states that the voltage difference between two points is the electric current flowing between them, and the resistance of the path of the current. Mathematically, the law states that $V = IR$, where V is the voltage difference, I is the current in amperes, and R is the resistance in ohms. The higher the voltage, the higher the electric current hence more electron exchange can happen with the positively charged hydrogen ion (Robert, 2008). The higher supply of voltage also results in the increase the speed of hydrogen formation from water thus a higher rate of HHO gas production (Haryati, 2014). Figure 2.3 shows by increasing the voltage supplied to the system, this results in a higher hydrogen flow rate produced from the electrolyser.

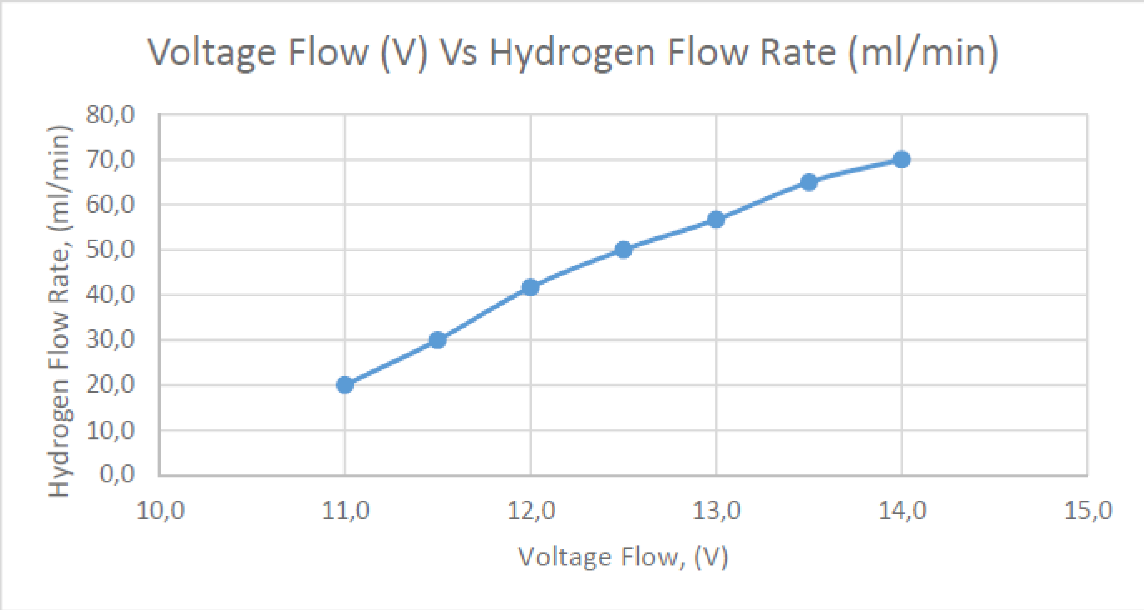


Figure 2.8: Hydrogen Gas Produced Per Minute In Respect To Voltage Flow In The Electrolyser (Nazry et. al., 2015)

2.4 Electrolyte

Electrolytic solution is a conductor solution and capable of conducting electrical current. The catalyst is a material that serves to accelerate the reaction by lowering the activation energy and not changing the reaction equilibrium, and is very specific. Electrolytes as catalysts in the electrolysis process can increase the reaction rate for breaking water molecules faster. By dissolving the electrolyte in water it will increase the electrical conductivity. Sodium Chloride (NaCl) is a common salt and is a typical example of electrolyte (Amikam et. al., 2018).

The concentration of catalyst (electrolyte) in water will affect the conductivity of the solution. The greater the volume of the electrolyte, resulted in greater conductivity of the catalyst molar, indicating that the ability of the solution to conduct electricity is greater or more easily flowing in the solution. The easier it flows at any time, then the solution can produce a larger electric current. When more electrolyte is adding the concentration of ions also increase causing more current to flow through the solution (Yuvaraj and Santhanaraj, 2014). The greater pH will also increase the hydrogen obtained. The hydrogen gas flow rate produced from the electrolyser only started to increases at certain pH value and continue to shows increment as the pH value increases (Nazry et. al., 2015).

2.4.1 Potassium Hydroxide (KOH)

Potassium hydroxide, KOH is a chemical compound, also known as caustic potash. Its original form is white solids and is sold commercially in the form of pellets or powders. A strong alkaline electrolyte solution uses potassium hydroxide (KOH) as its catalyst. The alkalinity of the solution allows electricity to be easily transferred from one cell to another as there are freely moving ions in the solution. It is also very corrosive to metals similar to strong acids. Its property of making the solution more electrically conductive is suitable for fuel cell applications (Wu et. al., 2014).

Potassium hydroxide, KOH is chosen to be the catalyst is because of the advantages that it can benefit for fuel cell applications. Among these advantages is the electrodes stay clean, making corrosion of the electrode plates more controlled. Besides, KOH can easily absorbs water vapor hence can dissolve quickly when added in the solution. KOH is known to have a high solubility in water of 1100g/L (Öhrström, 2015). In addition, potassium hydroxide also has its own disadvantages which are hard to find everywhere and require high security measures to be operated (Kaneco et. al., 2006).

Figure 2.9: Potassium Hydroxide (KOH) Pellets

2.5 Electrolysis Process

Water electrolysis is a process that involves the splitting of water into protons, electrons, and gaseous oxygen at the anode (positive electrode) and hydrogen at the cathode (negative electrode) by connecting DC supply to the electrodes (Momirlan and Veziroglu, 2005). It is the fundamental of working principles of a HHO generator to produce HHO gas or Brown gas (Subramanian and Ismail, 2018). The content of HHO gas are hydrogen gas (H_2) and oxygen gas (O_2) which are obtained from the results of decomposition process of water molecules (H_2O) by electrolysis method (Harman et. al., 2013). As water is abundance and readily available, producing HHO gas is rather cheap with today's technology.

In an electrolyzer, there are usually two electrodes (as anode and cathode) immersed in aqueous solution of electrolyte. Then, a DC supply is connected to the electrodes to complete the loop of electric current from the power supply, electrodes, and electrolyte. This will positively charge the anode with positive current which yields the electrolysis reaction of the electrolytic solution and eventually releases an enriched mixture of oxy-hydrogen gas or HHO gas.

In an alkaline electrolyzer, usually two electrodes, the cathode and the anode, connected to a DC supply are immersed into an aqueous electrolyte solution added with an alkaline compound or referred to as catalysts (Manabe et. al., 2013). The catalysts that are typically used are NaOH, KOH or NaCl for a more efficient and higher rate of HHO production. It is also vital to keep the balance of the cell's electrical resistance-conductivity by keeping an optimum molality of the catalyst. The migration or freely moving ions will result in a more efficient production of hydrogen at the cathode and oxygen at the anode (Géraldine et. al., 2011). Alkaline electrolysis is mostly preferred due to its rate of corrosion is easily controlled and cheaper construction materials as compared to acidic electrolysis technology. The equations at the respective electrodes are as follows:

Anode Reaction : $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

Cathode Reaction : $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

Overall Reaction : $2H_2 + O_2 \rightarrow 2H_2O$ + electric energy + heat

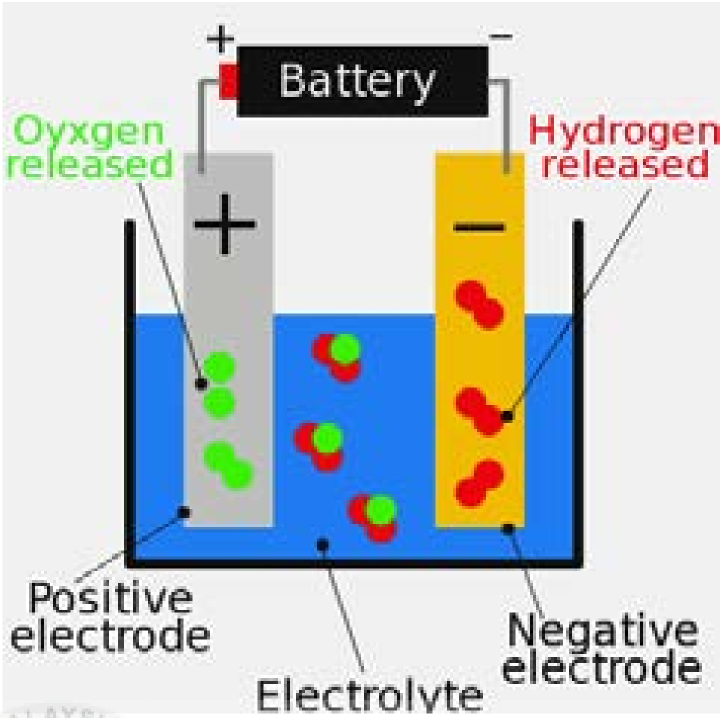


Figure 2.10: Alkaline Water Electrolysis

CHAPTER 3

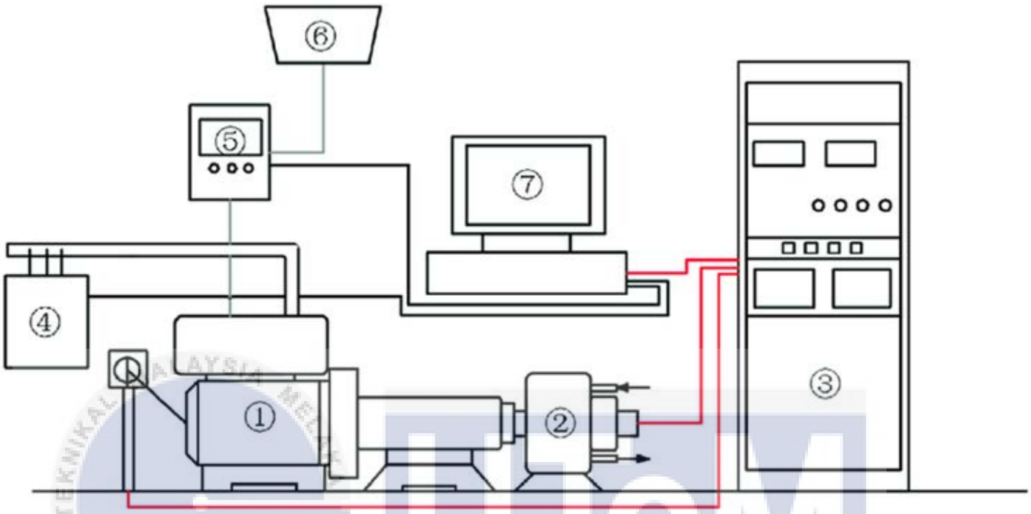
METHODOLOGY

This chapter describes the methodology used in this project to design and fabricate suitable HHO plate surface roughness for the engine, to analyse the flowrate of HHO gas produced with different plates' surface roughness, and to evaluate the engine's performance and emission from the commissioning of the HHO cell with the engine. The flow chart of the project is shown in Figure 3.1. The three main equipment used in this project are hybrid fuel cell, 150cc motorcycle SI engine, a dynamometer machine, and emission gas analyzer machine.

3.1 General Experimental Setup

The general experimental setup for this project is as shown in the schematic diagram in Figure 3.1. The experiment setup is done at Kompleks Makmal Kejuruteraan Mekanikal (KMK) UTeM where the lab for the dynamometer is being kept. The experiments involved are conducted to do a baseline test for the 150cc Motorcyle SI Engine to get the initial parameters of the engine before integrating it with a hybrid fuel cell. The baseline test is required as to compare the results obtained with the results when the engine is installed with the hybrid fuel cell. This is to enable the analysis of the engine's parameters that includes its power, torque and also the emission generated.

The flow chart in Figure 3.2 is to show the work flow or work steps required to complete a project. It covers all processes involved from the beginning of the project until the project is complete. The first step begins with the problem statement and ends with a complete report that needs to be submitted.



1. 150cc Motorcycle SI Engine 2. Dyno-mite Dynamometer 3. Control Panel
4. Exhaust gas analysis system 5. HHO Generator 6. Voltage DC Source 7. Monitor

Figure 3.1(a): Schematic Diagram of the General Experimental Setup

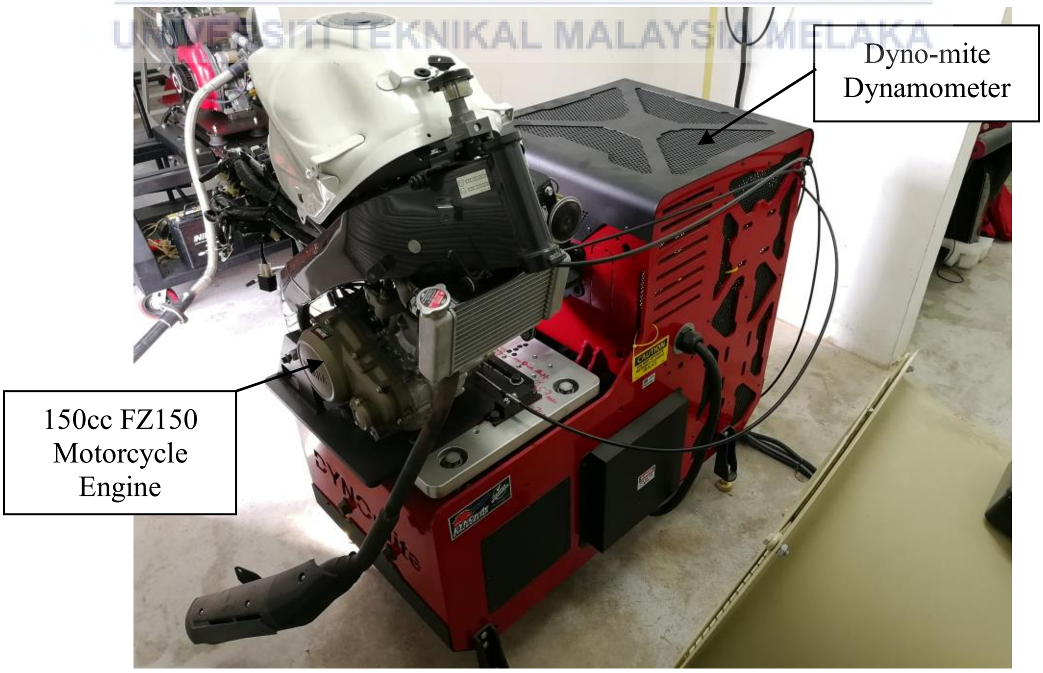


Figure 3.1(b): Actual Experimental Setup

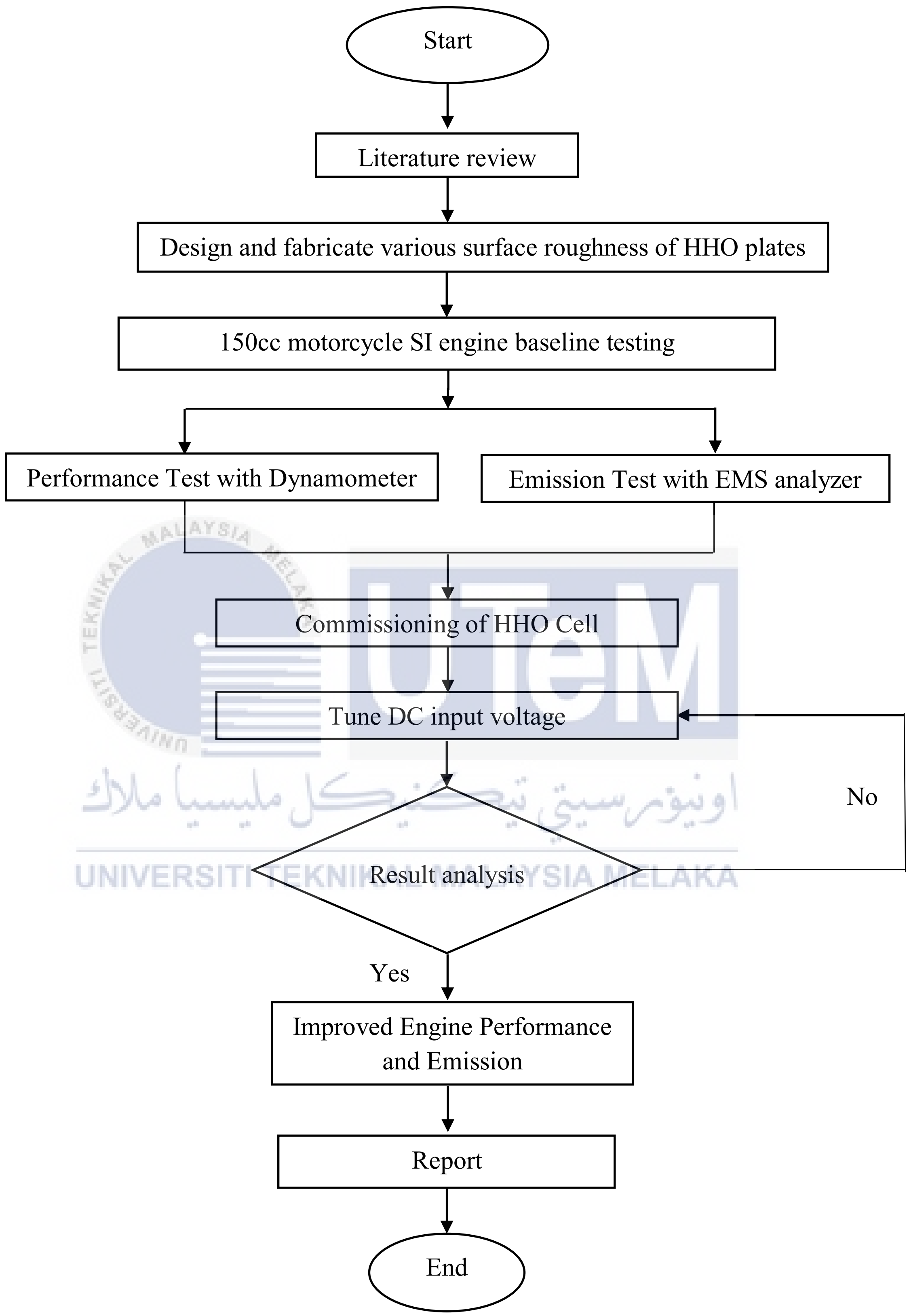


Figure 3.2: Project Flow Chart

3.1.1 150cc Motorcycle SI Engine

The 150cc motorcycle SI engine used in this study is the Yamaha FZ150 motorcycle engine. The engine draws power from a 149.8 cc, four-stroke, four-valve SOHC, liquid cooled engine that pumps out a maximum power of 12.2kW at 8,500 rpm and peak torque of 14.5 Nm at 7,500 rpm. The engine also features a fuel injection system for better mileage. As per Yamaha's claims, the FZ150 consumes 2.6-litre of fuel every 100 km and the fuel tank can store maximum 12-litre of fuel. Table 3.1 shows the engine specifications for Yamaha FZ150 engine and Figure 3.3 shows the Yamaha FZ150 engine taken out from chassis.

Table 3.1: Yamaha FZ150 Engine Specifications

Engine Type	4-Stroke, Liquid-cooled, SOHC, 4-Valve
No. of Cylinder	Single
Displacement	149.8 cm^3 @ 149.8 cc
Bore x Stroke	57.0 x 58.7 mm
Compression Ratio	10.4 : 1
Maximum Horsepower	12.2kW (8,500rpm)
Maximum Torque	14.5N.m (7,500rpm)
Starting System	Electric Starter
Lubrication System	Wet Sump
Engine Oil Capacity	1.15 litres
Fuel Tank Capacity	12.0 litres
Ignition System	Transistor Controlled Ignition (TCI)
Cooling System	Liquid-cooled
Battery Capacity Type	12V 3.5 Ah

Figure 3.3(a): Yamaha FZ150 Motorcycle Engine

Figure 3.3(b): Yamaha FZ150 Motorcycle Engine Specifications

3.1.2 Hybrid Fuel Cell

In this study, a hybrid fuel cell is used to supplement the air mixture of the intake manifold of the engine with HHO gas produced by the device. It is generally a device that splits the water molecule into its base components of hydrogen and oxygen ion or HHO gas. The basic working principle is it uses water electrolysis method by supplying a DC current to the electrodes in which results in a loop of continuous electric current connected through the electrolytic solution.

The hybrid fuel cell used in this study is alkaline fuel cell. There are two basic types of fuel cell: dry cell and wet cell. Hybrid fuel cell is selected in this study because it combines and maintains the efficiencies of both the wet and dry fuel cell resulting in a more efficient system. It is a series of HHO generator making process starting from the provisioning of SS316L plate material until assembling process becomes HHO generator cell. The next process combines the generator cell with the casing to become a functional HHO generator. After preparing the elements of the HHO generator, the next step is to combine these elements with the casing and complete it with the various accessories required. Figure 3.4 shows a hybrid-type HHO generator complete and ready to operate.

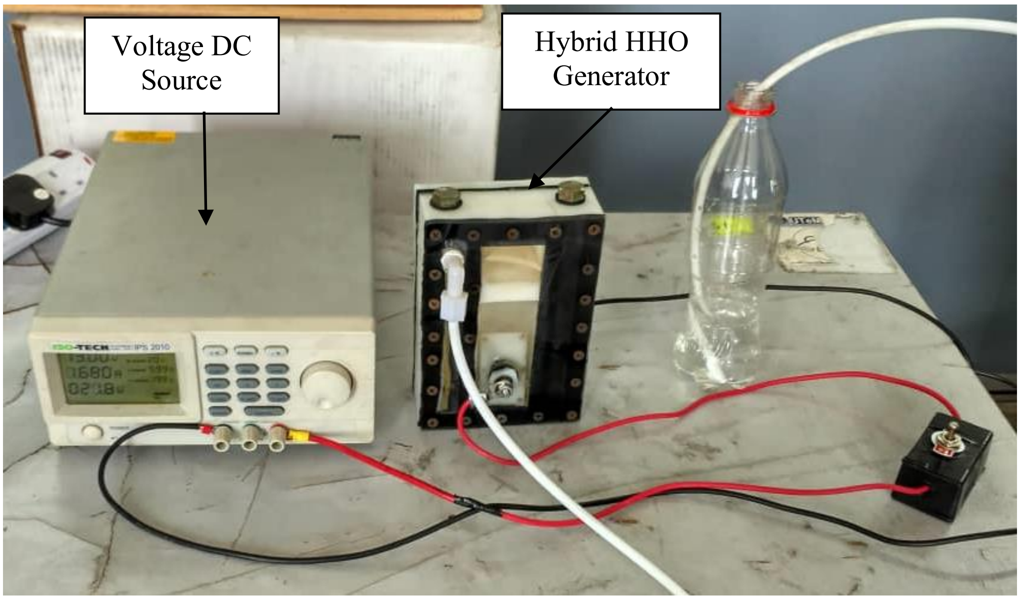


Figure 3.4: Hybrid HHO Generator Set-up

3.2 Fabrication Process

The plate chosen for this experiment is the stainless steel 316L. Various surface roughness of HHO plates are needed to test effects of the surface roughness to the production of HHO gas. The method used for polishing the plates is mechanical polishing. The HHO plates will be categorised into three types, namely non-polished, one-sided polished, and fully polished. The non-polished plates are maintained at its original surface roughness, while the fully polished plates are polished to mirror-like surface on both sides of the plates and the one-sided plates are only polished to mirror-like surface on one side of the plate.

3.2.1 Mechanical Polishing

In order to make the various surface roughness of the HHO plates, a grinder and polisher machine is used. The machine is called Pace Technologies Model NANO 2000T Grinder-Polisher machine as shown in Figure 3.5. To achieve mirror-like surface, the plates must go through grinding first only then polished. The first step in achieving the mirror-like surface is to grind the plates with a 400 grits sandpaper. Then, the plates are grind with a 800 grits sandpaper but in the opposite direction of the previous grinding. These are done to ensure that mirror-like surface can be achieved as grinding can get rid of the tiny grooves or holes on the surface of the plates. Finally, the plates are grind with a 2000 grits sandpaper before using a polishing chemical to polish the surface of the plates to achieve mirror-like surface.

Figure 3.5: Pace Technologies NANO 2000T Grinder-Polisher Machine

Figure 3.6: Samples of 400 Grits Sandpapers

3.3 Surface Roughness Test

The surface roughness of the plates are determined through both observation and measurements. For observation, the equipment used is Shodensha Metallographic Microscope Model GR3400 as shown in Figure 3.7. The microscope is connected to a desktop that runs WinRoof Software to be able to transfer and read the image from the microscope. The objective lens that are used are 5x, 10x, 20x, 40x, and 100x. After the images of the surface of the plates are taken, the plates' surface roughness are then measured with a handheld roughness tester TR200 as shown in Figure 3.8.

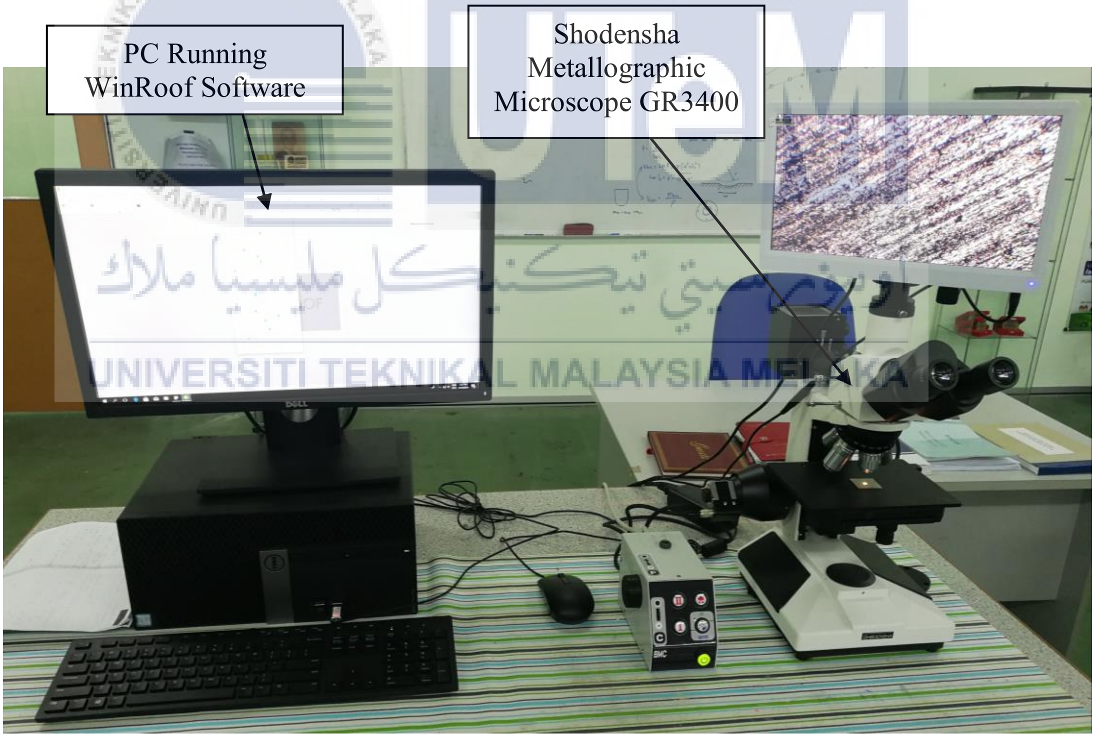


Figure 3.7: Shodensha Metallographic Microscope GR3400 Connected to PC Running WinRoof Software

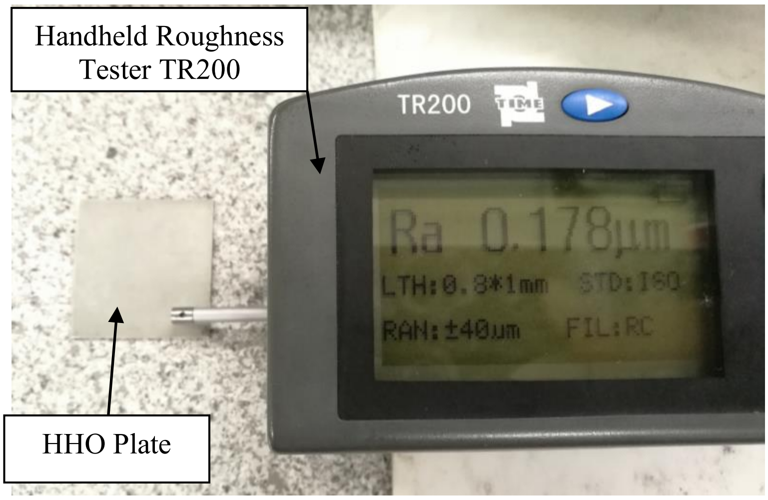


Figure 3.8: Surface Roughness Test with Handheld Roughness Tester TR200

3.4 Gas Flowrate Test

In order to measure the amount of HHO gas produced by the plates, a flow meter is used to collect the data. The results and data obtained is calculated by using a bottle of 500ml and drawn with 15 scales, so each scale contains 33.3333 ml of gas by dividing 500ml with 15 scales. The HHO gas produced (ml/s) is obtained by dividing 33.3333 ml or 1 scale with the time taken in second to reach 1 scale. Then, the results in ml/s will be multiplied by 60 to get the results in ml/min.

Figure 3.9: Flow Meter Used To Measure Flowrate Of HHO Gas Produced

3.5 Engine Test

The engine in this study is test for its performance in terms of power and torque and also the emission it generates. For the performance test, dyno-Mite dynamometer is used to run a baseline test as well as HHO cell integrated test. As for the emission test, an EMS machine is used to collect data of the emission that the engine generates before and after integrated with the HHO cell.

3.5.1 Performance Test

For the performance test, the analysis of the performance for the engine will be done in terms of its power and torque. The motorcycle engine will be run for three times to obtain a more reliable output. Before the experiment is conducted, make sure that all equipment connections have been made correctly. The engine will be set up on the dyno-mite dynamometer. The engine will running in Wide Open Throttle (WOT) simulation where data is collected from the lowest RPM to the highest RPM. The data and parameters of the engine performance will be collected from the dynamometer desktop DYNO-mite software. The data collected from this test before the commissioning of HHO gas will be used as the baseline while after the integration of HHO cell, the data collected will be used as comparison with the baseline data for performance analysis.

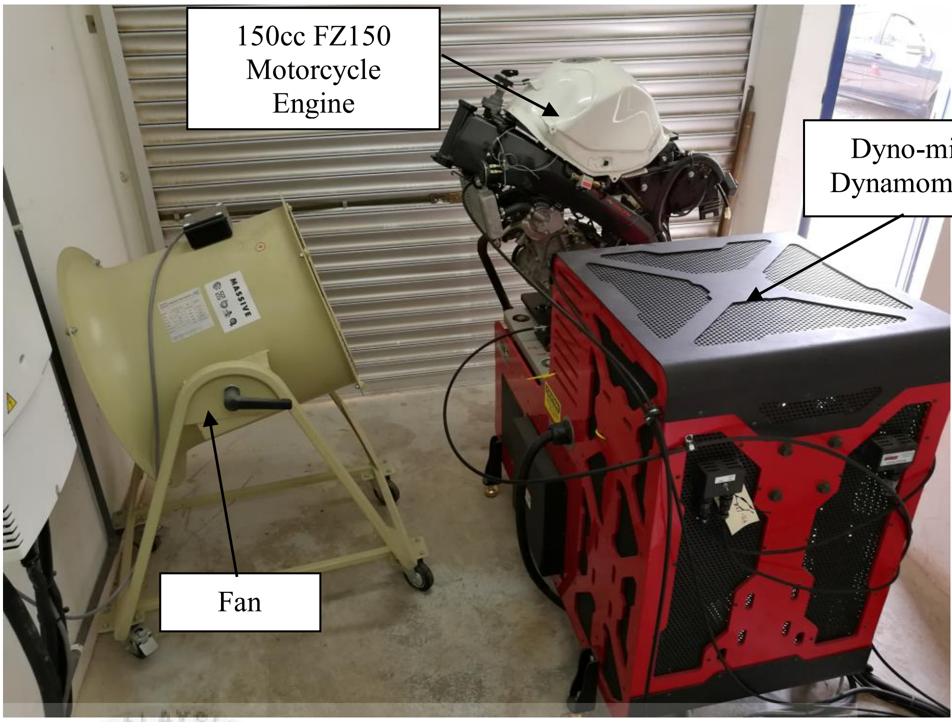


Figure 3.10: Dyno-mite Dynamometer Set-up

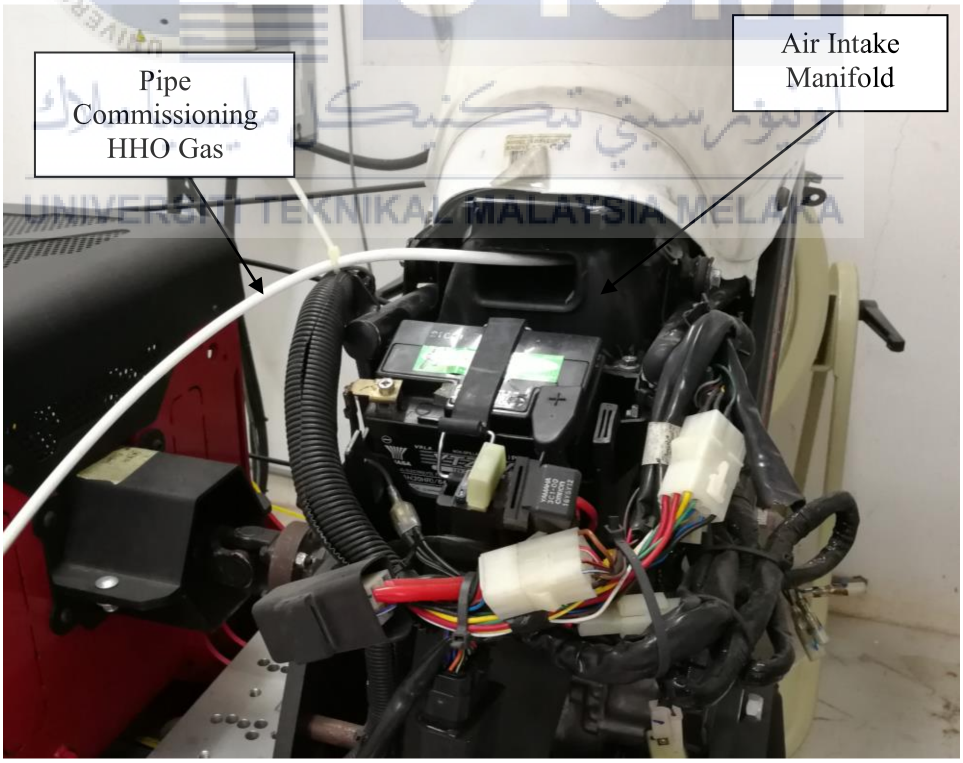


Figure 3.11: Commissioning of HHO Gas Into The Air Intake Manifold

Figure 3.12: Engine Dynamometer Specifications

3.5.2 Emission Test

For the emission test, it is conducted while the motorcycle engine will be running for three times to obtain a more reliable output. Before the experiment is conducted, make sure that all equipment connections have been made correctly. In this test, the EMS exhaust gas analyser will analyse the emission generated from the engine throughout the test. The flex tip that contains the sensor will put at the exhaust of the motorcycle to collect the emission data. Figure 3.12 shows the EMS Model 5002 exhaust gas analyser that is used.

Figure 3.13: EMS Model 5002 Exhaust Gas Analyser

Figure 3.14: Flex Tip Inserted Into The Motorcycle's Exhaust

CHAPTER 4

RESULTS AND DISCUSSION

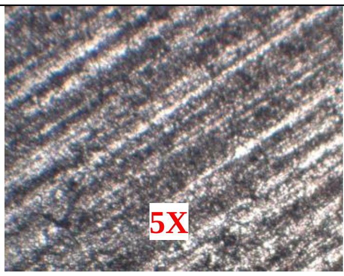
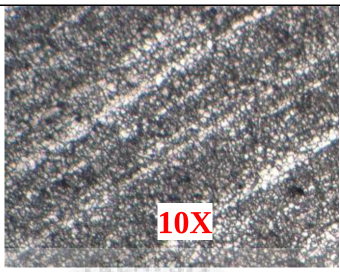
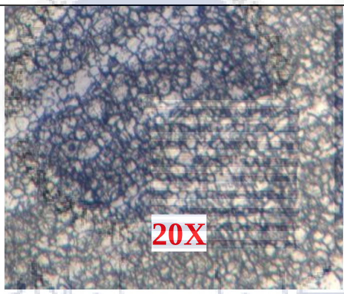
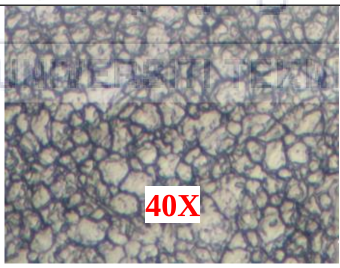
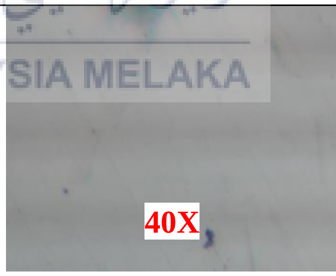
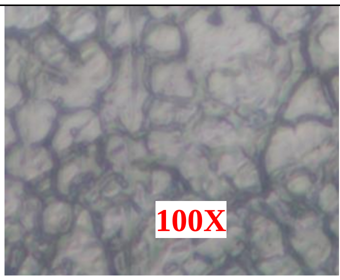
In this chapter, the results of before and after grinding and polishing of the plates will be shown in terms of observation and measurements. In addition, the results of the effect of surface roughness of the AISI 316L on the flowrate of hydrogen produced and the effect of adding HHO gas produced by the HHO generator to the air intake manifold of the motorcycle engine on the performance and emission will be shown. The experiment on the surface roughness of AISI 316L was conducted by using three different surface roughness of the plate, namely, non-polished, one-sided polished, and fully polished. The experiment was conducted to determine the highest flowrate of gas produced in ml/min unit. While the experiment on the performance of the motorcycle engine was conducted and analysed in terms of its power and torque. Besides, the emission test was also conducted to determine the effects of commissioning HHO gas into the air intake manifold in terms of Nitrogen Oxide (NOx), Carbon Monoxide (CO), Carbon Dioxide (CO_2), and Hydrocarbon (HC).

4.1 Surface Roughness

In the surface roughness tests, the tests are done with observation and measurements. Observation of the surface roughness of the plates is done by using Shodensha Metallographic Microscope connected to a desktop to be able to transfer and save the images captured through the microscope. The images are captured by using five different objective lens. The magnifications used are 5x, 10x, 20x, 40x, and 100x. Table 4.1 shows the observation of the surface roughness of the plates using the microscope with five different magnifications.

For the measurements of the surface roughness of the plates, handheld roughness tester TR200 is used to determine the roughness. The plates are tested at five different points on the surface. The data collected then will be averaged to obtain the most accurate data. Figure 4.0 shows the five different points on the plate that are to be measured. Table 4.2 shows the data collected for the non-polished plate and the fully polished plate.

Table 4.1: Surface Roughness of Plates With Five Different Magnifications

Non-Polished	Fully Polished (Mirror-like Surface)
	
	
	
	
	

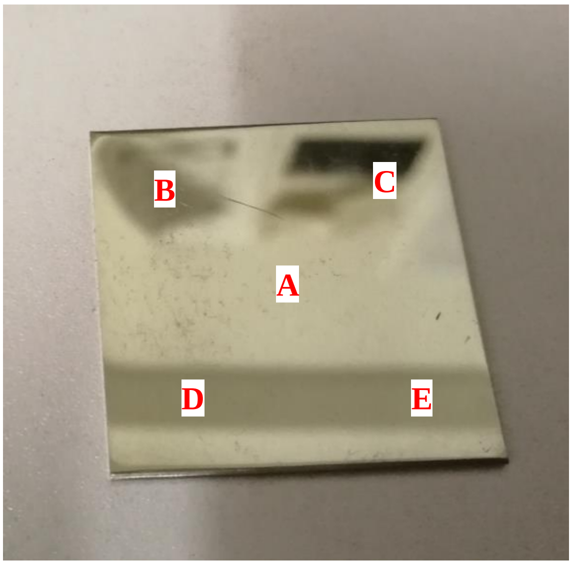


Figure 4.0: Five Different Points on the Plate for Surface Roughness Test

Table 4.2: Measurement of Surface Roughness of Plates At Five Different Points

Non-Polished	Point	Fully Polished (Mirror-like Surface)
0.150 µm	A	0.004 µm
0.132 µm	B	0.005 µm
0.137 µm	C	0.005 µm
0.173 µm	D	0.002 µm
0.178 µm	E	0.003 µm
0.154 µm	Average	0.004 µm

4.2 HHO Gas Flowrate

For the gas flowrate analysis, each experiment with the respective surface roughness of the AISI 316L plate was repeated three times and the results obtained were averaged together with the purpose of constructing the graphical representation. Figure 4.1 represents the graph of HHO gas produced against weight of KOH for non-polished plate, Figure 4.2 represents graph of HHO gas produced against weight of KOH for one-sided polished plate, and Figure 4.3 represents the graph of HHO gas produced against weight of KOH for fully polished plate. The reason to present the results in this way is to analyse the production of HHO gas with the input voltage of 12V, 13V and 14V and by consistently adding 5 grams of potassium hydroxide until the maximum of 25 grams. Graphical representation of comparison between the three surface roughnesses against HHO gas produced is shown in the comparative analysis in Figure 4.4.

In this test, there are three types of different surface roughness of HHO plate being tested. The first test conducted was on the non-polished HHO plate where the original surface roughness of the plate is maintained. The second test was conducted on the one-sided polished HHO plate where the plate is only polished on one side of the plate whilst the other side is maintain at its original surface roughness. The third test was conducted on the HHO plate that had been polished on both side of the plate. The results and data obtained is calculated by using a bottle of 500ml and drawn with 15 scales, so each scale contains 33.3333 ml of gas by dividing 500ml with 15 scales. The HHO gas produced (ml/min) is obtained by dividing 33.3333 ml or 1 scale with the time taken in second to reach 1 scale multiply by 60 to get the results in ml/min.

4.2.1 Non-Polished Plate

Figure 4.1 shows the HHO gas produced in ml/min by the non-polished plate when 5 grams of KOH was consistently added and supplied with input voltage of 12V, 13V, and 14V. The maximum weight of potassium that can be used is 25 grams.

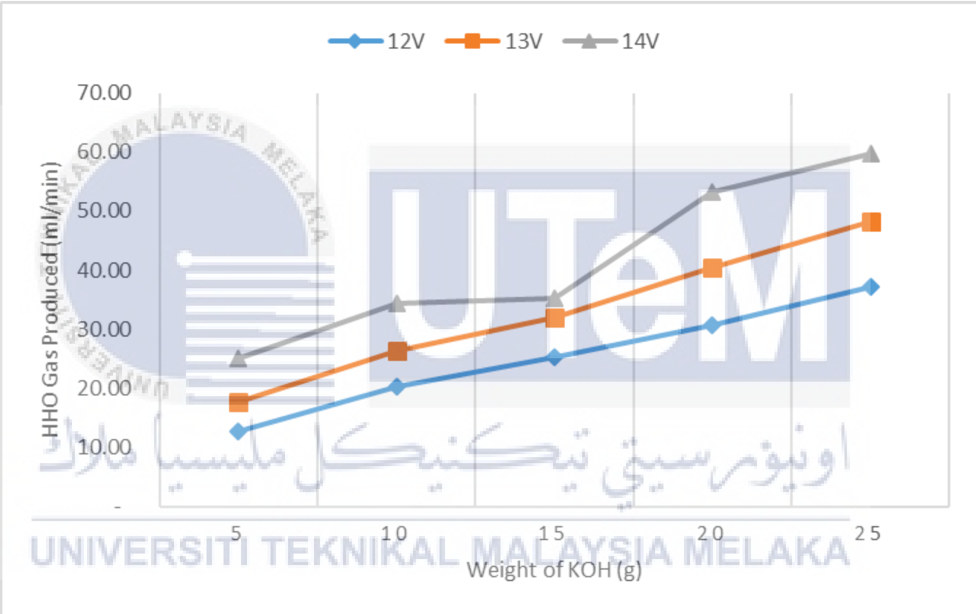


Figure 4.1: Graph of HHO Gas Produced against Weight of KOH for Non-Polished Plate

Based on Figure 4.1, the highest HHO gas produced by the non-polished plate when supplied with 12V is 37.27 ml/min. The gas flowrate is obtained when 25 grams of potassium hydroxide is used as catalyst. When 5 grams of potassium hydroxide is used, the HHO gas produced by the non-polished plate is 12.75 ml/min which is also the minimum gas flowrate obtained if supplied with 12V. The difference is almost doubled gas produced when the maximum amount of catalyst is used. When 10 grams, 15 grams, and 20 grams of potassium hydroxide are used, the HHO gas produced by the non-polished plate are 20.22 ml/min, 25.22 ml/min, and 30.78 ml/min respectively.

When the non-polished plate is supplied with 13V, the highest HHO gas produced is 48.22 ml/min when 25 grams of potassium hydroxide is used. The minimum gas flowrate obtained is 17.78 ml/min when 5 grams of potassium hydroxide is used. The HHO gas produced are 26.45 ml/min, 32.01 ml/min, and 40.41 ml/min when 10 grams, 15 grams, and 20 grams of potassium hydroxide are used respectively.

Besides, it is shown that the maximum HHO gas produced is 59.79 ml/min when supplied with 14V and 25 grams of potassium hydroxide is used. While 24.97 ml/min of HHO gas is produced when 5 grams of potassium hydroxide is used. When 10 grams, 15 grams, and 20 grams of KOH are used, the HHO gas produced are 34.36 ml/min, 35.26 ml/min, and 53.16 ml/min.

Based on the data obtained, it can be said that the highest flowrate of HHO gas produced is 59.79 ml/min when it is supplied with 14V and 25 grams of KOH used whereas the lowest HHO gas produced is 12.75 ml/min when connected to a 12V input and 5 grams of KOH is used.

4.2.2 One-Sided Polished Plate

Figure 4.2 shows the HHO gas produced in ml/min by the one-sided polished plate when 5 grams of KOH was consistently added and supplied with input voltage of 12V, 13V, and 14V. The maximum weight of potassium that can be used is 25 grams.

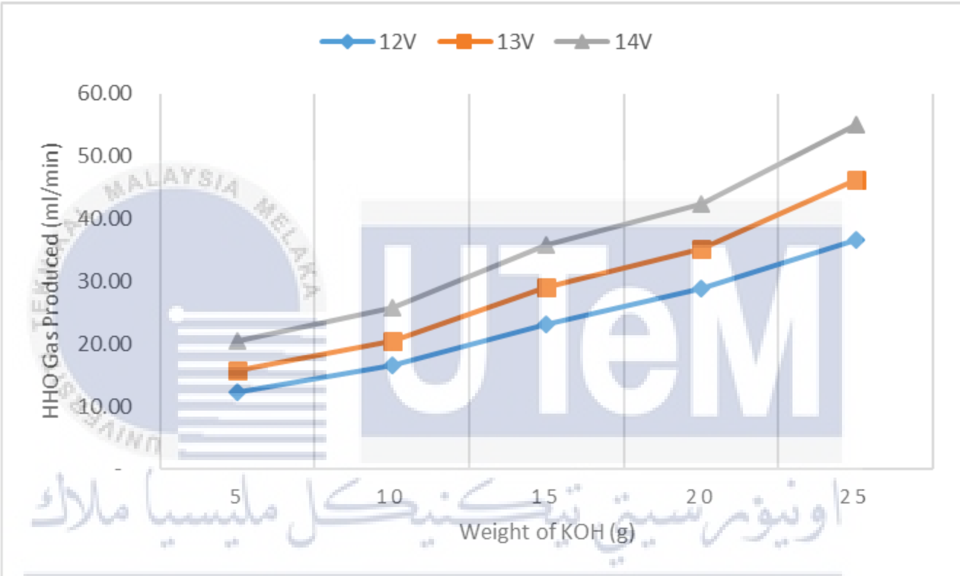


Figure 4.2: Graph of HHO Gas Produced against Weight of KOH for One-Sided Polished Plate

Based on Figure 4.2, when 5 grams of potassium hydroxide is used, the HHO gas produced by the one-sided polished plate is 12.24 ml/min which is also the minimum gas flowrate obtained when supplied with 12V. The highest HHO gas produced by the one-sided polished plate when supplied with 12V is 36.58 ml/min when 25 grams of potassium hydroxide is used as catalyst. The difference is also almost doubled the amount of gas produced when the maximum amount of catalyst is used. When 10 grams, 15 grams, and 20 grams of potassium hydroxide are used, the

HHO gas produced by the one-sided polished plate are 16.56 ml/min, 23.08 ml/min, and 28.90 ml/min respectively.

When the one-sided polished plate is supplied with 13V, the highest HHO gas produced is 46.15 ml/min when 25 grams of potassium hydroxide is used. The minimum gas flowrate obtained is 15.71 ml/min when 5 grams of potassium hydroxide is used. When 10 grams, 15 grams, and 20 grams of potassium hydroxide are used, the HHO gas produced are 20.37 ml/min, 29.12 ml/min, and 35.22 ml/min respectively.

Besides, when supplied with 14V and 25 grams of potassium hydroxide is used, it is shown that the maximum HHO gas produced is 55.08 ml/min. While 20.37 ml/min of HHO gas is produced when 5 grams of potassium hydroxide is used. The HHO gas produced are 25.77 ml/min, 35.74 ml/min, and 42.35 ml/min when 10 grams, 15 grams, and 20 grams of KOH are used respectively.

Based on the data obtained, it can be said that the highest flowrate of HHO gas produced is 55.08 ml/min when it is supplied with 14V and 25 grams of KOH used. But it is 8.55% lower in the production of HHO gas when compared to using non-polished plate. While the lowest HHO gas produced is 12.24 ml/min when connected to a 12V input and 5 grams of KOH is used which is lower by 4.17% in comparison with non-polished plate.

4.2.3 Fully Polished Plate

Figure 4.3 shows the HHO gas produced in ml/min by the fully polished plate when 5 grams of KOH was consistently added and supplied with input voltage of 12V, 13V, and 14V. The maximum weight of potassium that can be used is 25 grams.

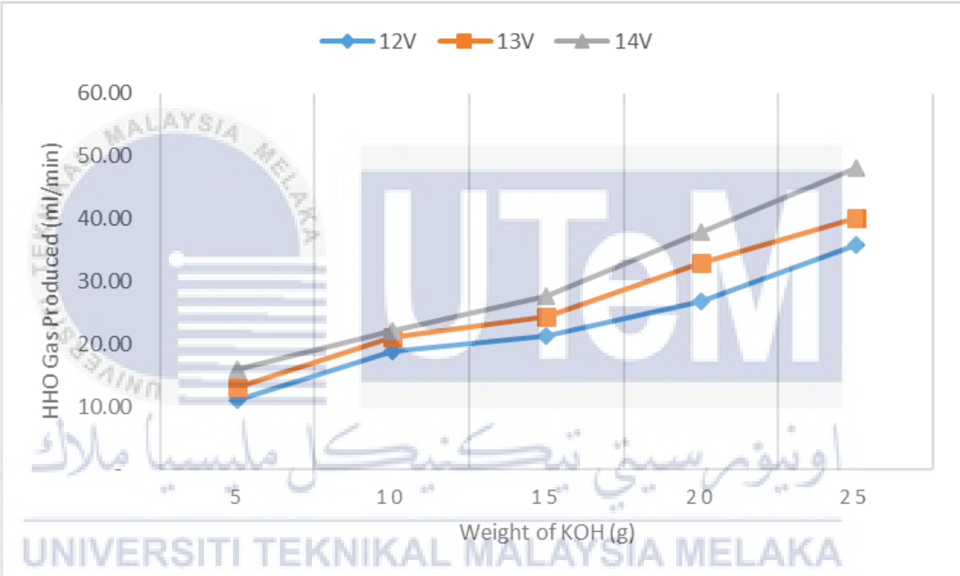


Figure 4.3: Graph of HHO Gas Produced against Weight of KOH for Fully Polished Plate

Based on Figure 4.3, the lowest HHO gas produced by the fully polished plate is 11.05 ml/min when supplied with 12V and 5 grams of KOH is used which is the minimum obtained in this test. While the highest HHO gas produced by the fully polished plate when supplied with 12V is 35.71 ml/min when 25 grams of potassium hydroxide is used as catalyst. When 10 grams, 15 grams, and 20 grams of potassium hydroxide are used, the HHO gas produced by the non-polished plate are 18.75 ml/min, 21.33 ml/min, and 26.71 ml/min respectively.

In addition, when the one-sided polished plate is supplied with 13V, the highest HHO gas produced is 40.06 ml/min when 25 grams of potassium hydroxide is used. The minimum gas flowrate obtained is 13.17 ml/min when 5 grams of potassium hydroxide is used. The HHO gas produced are 21.15 ml/min, 24.28 ml/min, and 32.87 ml/min when 10 grams, 15 grams, and 20 grams of potassium hydroxide are used respectively.

Besides, it is clear that the maximum HHO gas produced is 48.08 ml/min when supplied with 14V and 25 grams of potassium hydroxide is used. When 5 grams of potassium hydroxide is used, 24.97 ml/min of HHO gas is produced. When 10 grams, 15 grams, and 20 grams of KOH are used, the HHO gas produced are 22.16 ml/min, 27.51 ml/min, and 37.86 ml/min.

Based on the data obtained, the one-sided plate produces the highest flowrate of HHO gas at 48.08 ml/min when it is supplied with 14V and 25 grams of KOH used. This is lower by 24.46% when compared with non-polished plate under the same condition. When connected to a 12V input and 5 grams of KOH is used, the lowest HHO gas produced is 11.05 ml/min which is lower by 15.38% when compared with non-polished plate.

4.2.4 Comparative Analysis

Figure 4.4, Figure 4.5, and Figure 4.6 show the comparison of HHO gas produced against weight of KOH for three different surface roughness with 12V, 13V, and 14V input voltage respectively. 5 grams of KOH was consistently added until the maximum weight of potassium that can be used that is 25 grams.

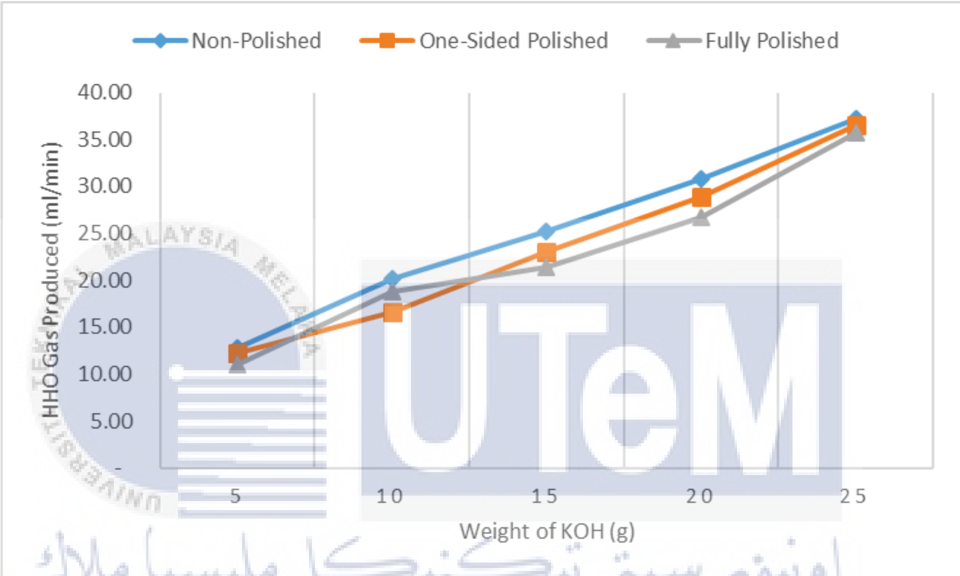


Figure 4.4: Comparison of HHO Gas Produced against Weight of KOH for Three Different Surface Roughness with 12V input

Based on Figure 4.4, the graph shows an upward trend of output current when consistently added with KOH as the catalyst. In comparison, the non-polished plate has the highest HHO gas produced when added with 25 grams of KOH with a value of 37.27 ml/min while the lowest HHO gas produced is 35.71 ml/min when fully polished plate is used. It indicates an increase of 4.37% of HHO gas produced when non-polished plate is used. This shows that when the plate is not polished or retain its original roughness, the electrical conductivity of the plate increases as it has the roughest or the highest relative roughness factor. The higher the roughness or relative roughness factor, the higher the effective surface area for the electrolysis process to occur. Hence, more surface area for the electrolysis process to occur and able to produce more HHO gas given the same condition. This increases the efficiency of the electrolysis process because higher roughness leads to higher effective surface area to produce more HHO gas.

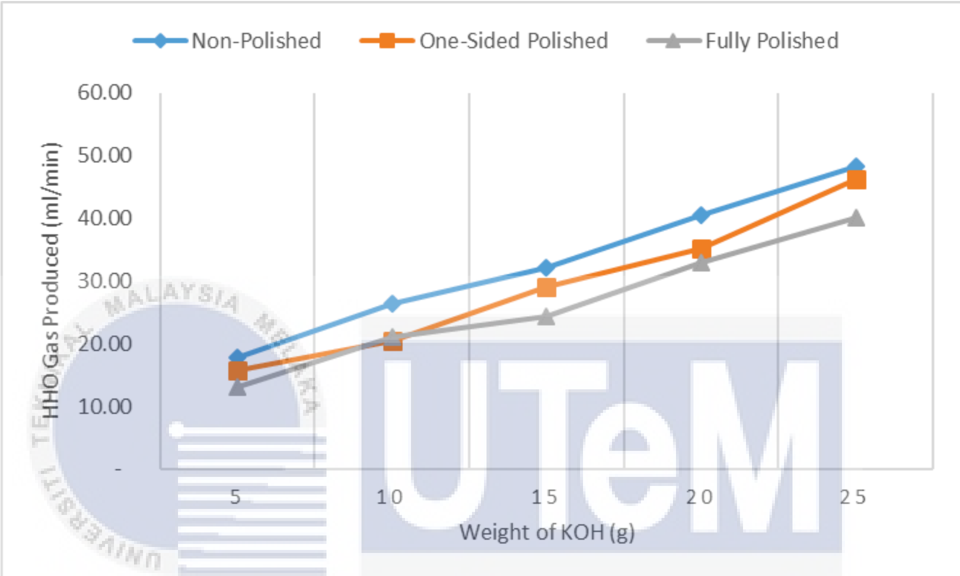


Figure 4.5: Comparison of HHO Gas Produced against Weight of KOH for Three Different Surface Roughness with 13V input

Based on Figure 4.5, while comparing the HHO gas produced of the three surface roughness plates, it is clear that the non-polished plate produced the highest amount of HHO gas at 48.22 ml/min when added with 25 grams of KOH. In contrast, the fully polished plate produced only 40.06 ml/min of HHO gas under the same condition. This indicates that the surface roughness of the plate affects tremendously to the output current needed and the increase in HHO gas produced is 20.37%. Besides, it is shown that from 5 grams to 15 grams of KOH used, the HHO gas produced for one-sided polished and fully polished plate are fluctuating. This is maybe due to the inconsistency in the weight of KOH used in which results in the data being inaccurate.

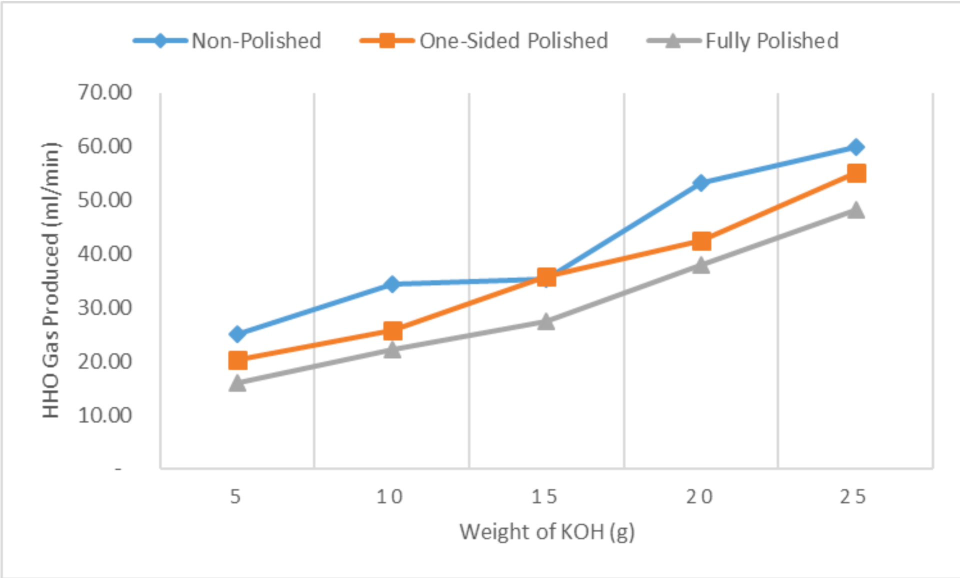


Figure 4.6: Comparison of HHO Gas Produced against Weight of KOH for Three Different Surface Roughness with 14V input

Based on Figure 4.6, it is clearly shown that more efficient electrolysis process occurred when catalyst is consistently added until the maximum of 25 grams. By comparing the three surface roughness plates at 25 grams of KOH, it indicates that the highest HHO gas produced is 59.79 ml/min when used with non-polished plate. While the lowest HHO gas produced is 48.08 ml/min by the fully polished plate. The increase in HHO gas produced is 11.71 ml/min or 24.36%. It can be concluded that the rougher the surface of the plate, the higher the effective surface area for electrolysis process to occur. This is shown that the non-polished plate has the roughest surface which indicates higher effective surface area hence contributes to a more efficient electrolysis process (Zeng et. al., 2014).

4.3 Performance Analysis

Figure 4.7 shows the graph of power against engine speed for baseline and with HHO gas addition and Figure 4.8 represents the graph of torque against engine speed for baseline and with HHO gas addition. Both experiments were conducted with Wide Open Throttle (WOT) simulation to test its power and torque from 2100 RPM to 8700 RPM.

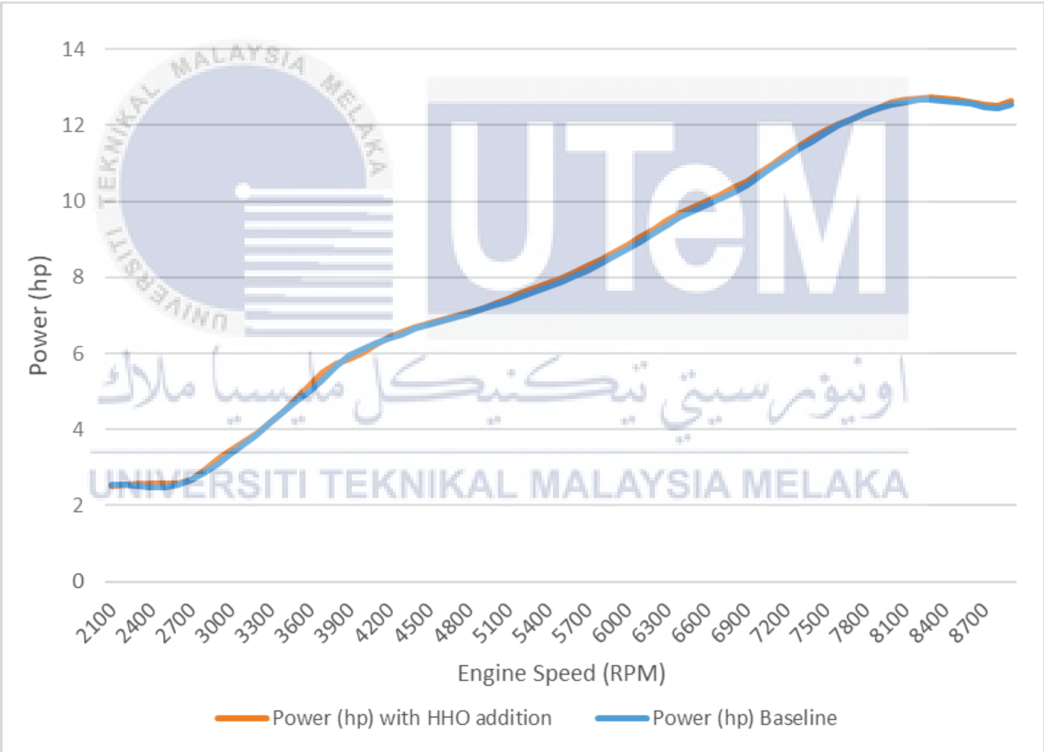


Figure 4.7 : Graph of Power against Engine Speed for Baseline and With HHO Addition

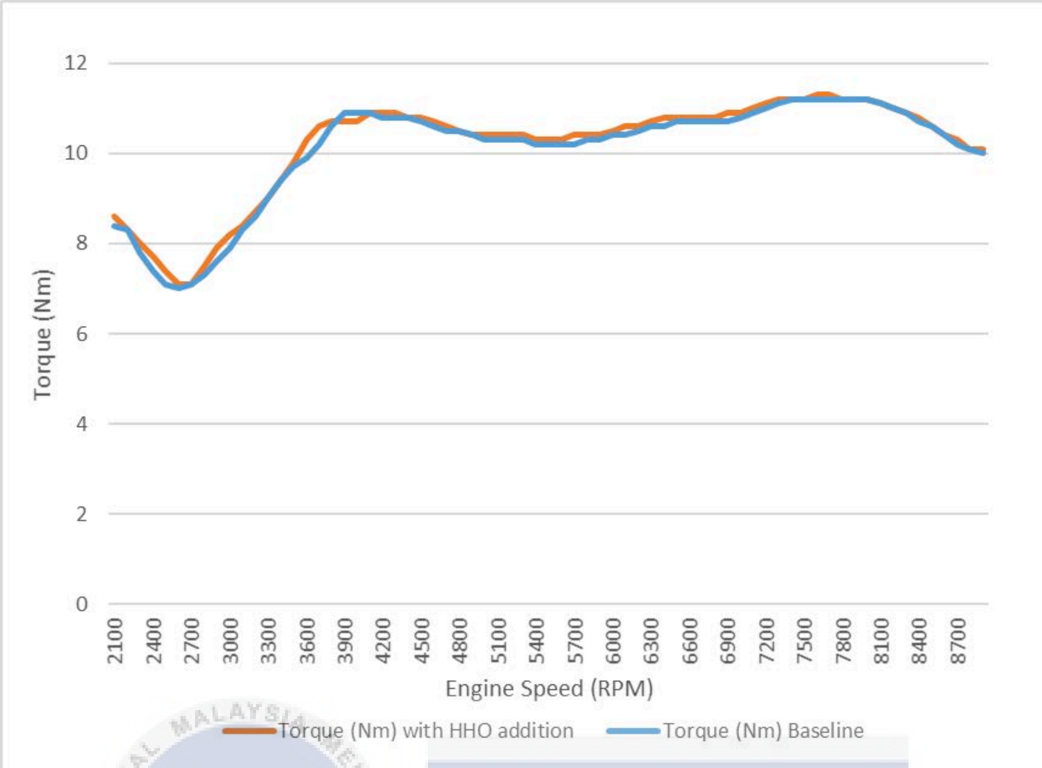


Figure 4.8 : Graph of Torque against Engine Speed for Baseline and With HHO Addition

Based on Figure 4.7, it represents the comparison of the power against engine speed for baseline and when added with HHO gas. It is clear that from the graph, there are increases and decreases in certain RPM that shows the power of the engine fluctuates in the baseline and when incorporated with HHO gas. Both power peak at the engine speed of 8300 RPM, at which for the baseline the power is 12.67 hp whereas when added with HHO gas is 12.72 hp. While comparing the peak horsepower at 8300 RPM of baseline and with the addition of HHO gas, there is an increase of only 0.05 hp or 0.4% in terms of horsepower. It can be concluded that the overall pattern of power for the engine increased by only a margin.

Based on Figure 4.8, it is shown that there is a minimal fluctuation occurs in the baseline and with HHO gas added for the torque produced from 2100 RPM to 8700 RPM. In comparison, the peak torque produced in baseline is 11.2 Nm at the engine speed of 7700 RPM, whereas the peak torque produced when commissioned with HHO gas is 11.3 Nm at engine speed of 7700 RPM. This shows that there is a marginal increase in torque produced by the engine when added with HHO gas. The increase in torque is only 0.1 Nm or 0.89% increment in terms of torque.

With the increment in power and torque produced by the engine, it is shown that with the commissioning of HHO gas does increase the engine performance although by just a margin. It is safe to say that the air-fuel mixture with addition of HHO gas has greater value in terms burning value or heating value. Theoretically, the performance of the engine is greatly affected by the mixture of fuel that goes into its combustion chamber. The burning or heating value, or better known as the calorific value, of the air-fuel mixture that is higher is assumed to be more powerful. This is because the calorific value of hydrogen is three times more than fuel alone. It is also noted that the chemical composition of the HHO gas exists as two atoms whereas gasoline fuel contains thousands of bulky molecules of hydrocarbon. In a conducive combustion, the HHO gas ignites through the cylinder wall at much greater speed than in a normal air-fuel mixture. This leads to a more efficient combustion as combustion will be much closer to top dead centre (TDC) where it has a chance to turn into mechanical torque (rotary push) the right way and without pinging. Each piston transfers more energy during its combustion cycle so combustion becomes more efficient as well as more efficient ignition process thus will increase the performance of the engine and also lessen the unburnt fuel that will release as harmful emission (Musmar et. al., 2011).

4.4 Emission Analysis

HHO gas is always known as the new source of energy in the auto energy sector. Due to its high burning and reactive property, when incorporated into the air intake manifold of the engine, it will increase the combustion efficiency which directly affects the emission produced. For the emission test, exhaust gas analyser (EMS-5002) was used to measure the emissions, namely, Nitrogen Oxide (NOx), Carbon Monoxide (CO), Carbon Dioxide (CO_2), and Hydrocarbon (HC). In addition, analysis of the emissions with and without the addition of HHO gas was done on the reduction of the exhaust gases, such as NOx, CO, CO2, and HC, which are air pollutants and harmful for human health and the environment.

4.4.1 Nitrogen Oxide (NOx)

Figure 4.9 shows the graph of NOx against engine speed for baseline and with HHO gas addition. The experiment was conducted with Wide Open Throttle (WOT) simulation to test its NOx emission from 2100 RPM to 7300 RPM.

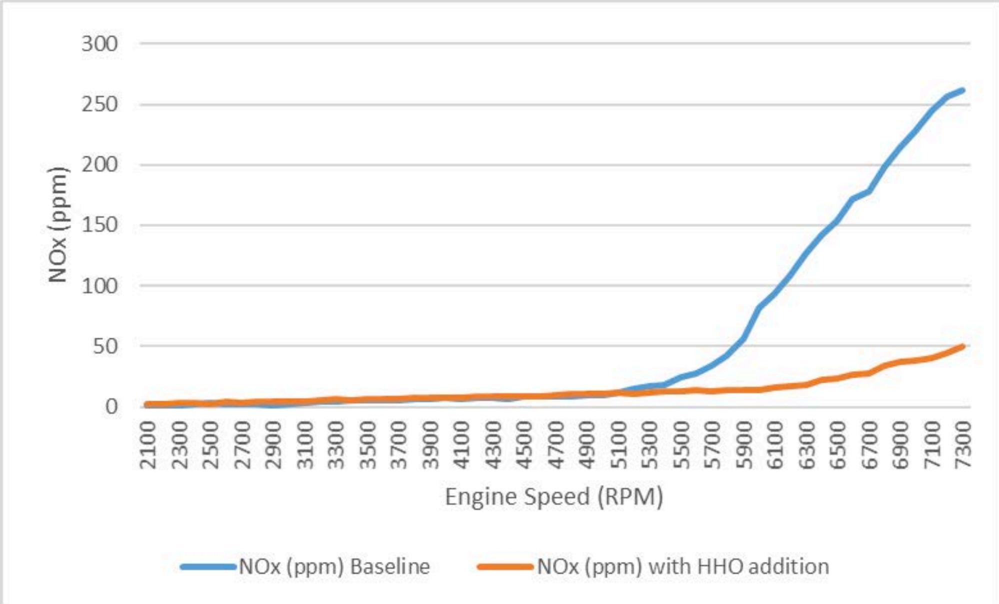


Figure 4.9 : Graph of NOx against Engine Speed for Baseline and With HHO Addition

The comparison of emission of nitrogen oxide (NOx) when the engine is incorporated with and without HHO gas is shown in Figure 4.9. From the engine speed of 2100 RPM to 5000 RPM, the emission of NOx is almost similarly as the difference is very minimal. Great reduction of NOx is clearly shown starting at the engine speed of 5100 RPM where the emission from baseline starts to increase exponentially until at the engine speed of 7300 RPM. While the emission of NOx with HHO gas addition shows a much slower increase in NOx emission until it reaches the engine speed of 7300 RPM. In comparison, at engine speed of 7300 RPM, the emission of NOx for baseline reached 262 ppm while when added with HHO gas it only reached 50 ppm. The reduction of NOx emission taken at engine speed of 7300 RPM is 80.92%.

Nitrogen oxide is formed when oxygen and nitrogen atoms are combined at high pressure. It the main cause of acid rain and can also form ozone in the atmosphere as it binds with hydrocarbons. High flame temperature and surplus air contributes to high NOx emission. When HHO gas is commissioned into the air intake manifold of the engine, it results in reducing the air-fuel ratio in which leads to a leaner mixture. A lean mixture will cause higher flame temperature due to the excess of oxygen as compared to the fuel. But in this case, when added with HHO gas, it can be said that the leaner mixture is due to the addition or excess of HHO gas in which will not result in higher flame temperature. This is because HHO gas exists as tiny independent clusters of no more than two atoms (diatomic) per combustible unit. It results in efficient combustion because the hydrogen and oxygen atoms interact directly without any ignition propagation delays due to surface travel time of the reaction. On ignition, its flame front flashes through the cylinder at a much higher velocity than in ordinary gasoline/air combustion (Fanhua et. al, 2010). It generates heat and pressure wave that will crush the gasoline droplets, and expose the fuel from their interior to the oxygen. This leads to more effective combustion as it enriches the air-fuel ratio because more fuel is available to be burnt. The crushed fragments of fuel will then be ignited thus producing more energy in a shorter time frame. Therefore, lower NOx emission is obtained after incorporating HHO gas into the air intake manifold as it enhances the combustion characteristics of the engine.

4.4.2 Carbon Monoxide (CO)

Figure 4.10 shows the graph of CO against engine speed for baseline and with HHO gas addition. The experiment was conducted with Wide Open Throttle (WOT) simulation to test its NOx emission from 2100 RPM to 7300 RPM.

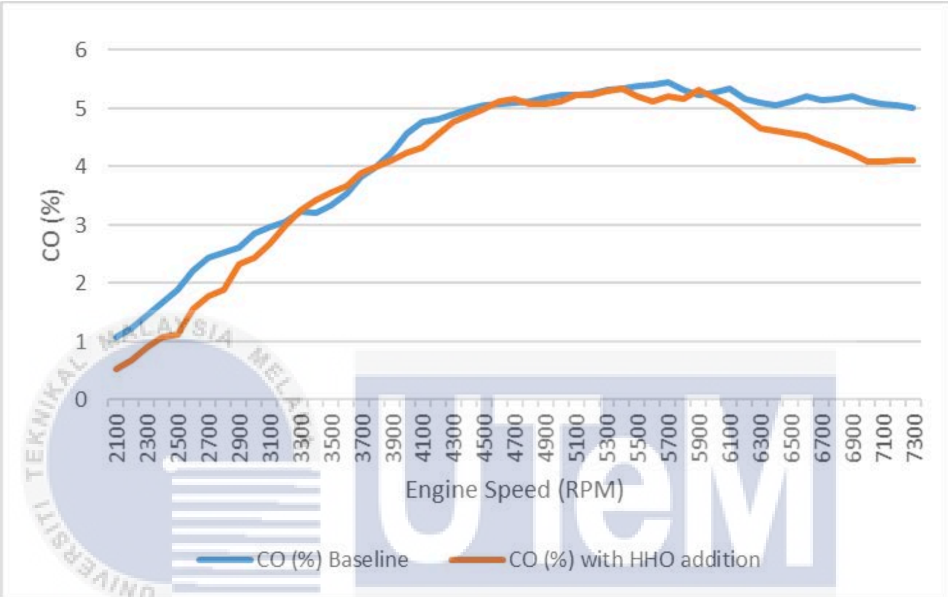


Figure 4.10 : Graph of CO against Engine Speed for Baseline and With HHO Addition

The effect of adding HHO gas to the engine on the carbon monoxide concentration is presented in Fig. 4.10. From the engine speed of 2100 RPM to 3300 RPM, it is shown that the CO emission is reduced by 30% to 40%. But at engine speed of 3400 RPM to 3800 RPM, it shows that there is a slight increase of 5% to 10% in CO emission when added with HHO gas. While the engine speed is at 3900 RPM to 5900 RPM, there is a slight increase in reduction of CO emission with an average of 15%. When at engine speed of 6000 RPM to 7300 RPM, the reduction of

CO is at an average of 25.49%. This clearly shows that the reduction of CO emission occurs the highest at lower engine speed of 3300 RPM and below.

Carbon monoxide forms when the fuel manages to be partially oxidized instead of completely oxidized into carbon dioxide. It is very toxic to humans as it can reduce or stop oxygen from getting to the brain. The reduction of CO emission is affected by the air-fuel ration of the engine. When HHO gas is added to the engine, this reduces the air-fuel ratio in which will greatly reduce the emission of CO due to higher efficient combustion characteristics and higher thermal efficiency.

4.4.3 Carbon Dioxide (CO_2)

Figure 4.11 shows the graph of CO_2 against engine speed for baseline and with HHO gas addition. The experiment was conducted with Wide Open Throttle (WOT) simulation to test its NOx emission from 2100 RPM to 7300 RPM.

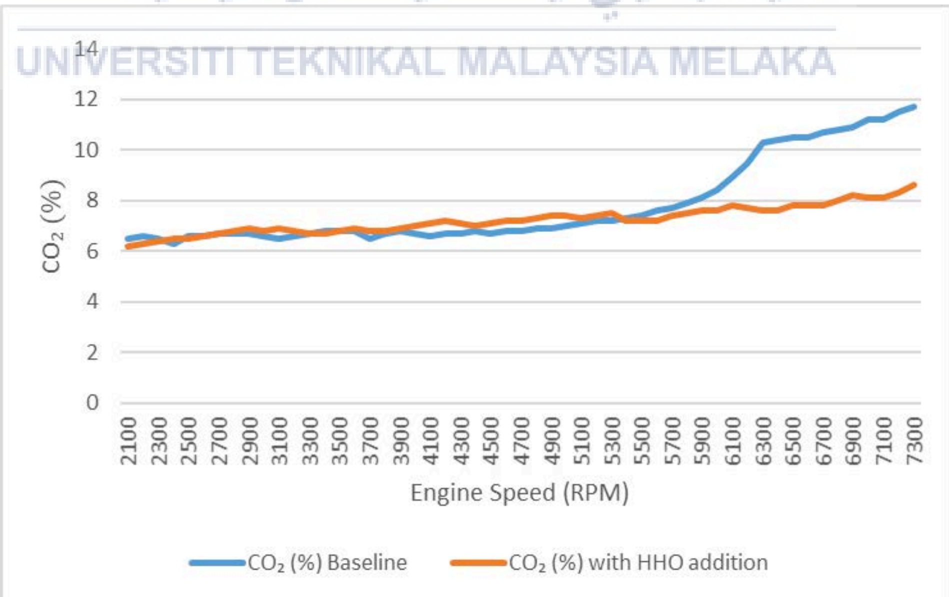


Figure 4.11 : Graph of CO_2 against Engine Speed for Baseline and With HHO Addition

The variation of carbon dioxide concentration in the exhaust with engine speed is presented in Figure 4.11. From the figure, it is shown that there are two segments in the graph. The first segment is at engine speed of 2100 RPM to 5400 RPM where there is actually a very minimal increase of carbon dioxide emission of below 3% when commissioned with HHO gas. While at engine speed of 5500 RPM to 7300 RPM, it is clearly shown that there is a great reduction in carbon dioxide emission when added with HHO gas. The highest reduction of carbon dioxide emission occurs at higher engine speed with an average decrease of 34%. This can be related to the shorter combustion time at higher engine speed where without the addition of HHO gas, more incomplete combustion occurs thus producing higher emission of carbon dioxide.

Carbon dioxide is one of the main greenhouse gases contributing to the increased temperature of the earth's atmosphere. As HHO gas is not a fossil fuel, and exist as only hydrogen and oxygen, it results in being more environmental-friendly and less carbon dioxide emission from the commissioning of HHO gas into the engine.

4.4.4 Hydrocarbon (HC)

Figure 4.12 shows the graph of HC against engine speed for baseline and with HHO gas addition. The experiment was conducted with Wide Open Throttle (WOT) simulation to test its NOx emission from 2100 RPM to 7300 RPM.

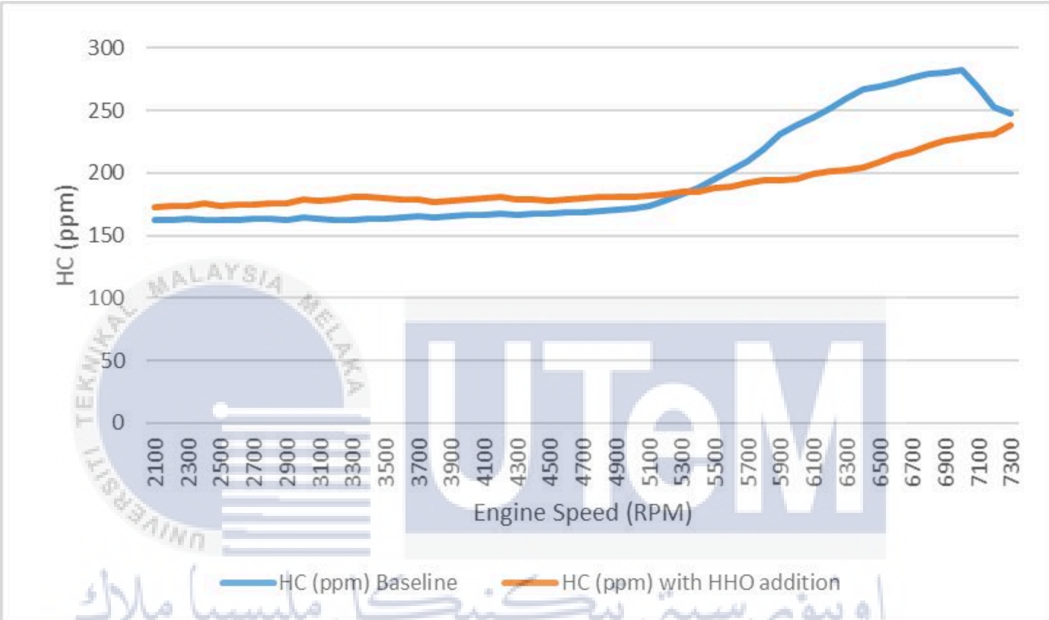


Figure 4.12 : Graph of HC against Engine Speed for Baseline and With HHO Addition

Based on Figure 4.12, it is clearly shown that there are also two segments in this graph. The first segment shows at engine speed of 5300 RPM and below, there is a slight increase in HC emission at about 10% when added with HHO gas. This is maybe due to the fact that there is lack of time for the HHO gas to enter the combustion chamber thus produces higher HC emission. At engine speed of 5400 RPM and above, it is very clear that as enough HHO gas has entered the combustion chamber, there is a great reduction of HC emission. The highest decrease in HC emission occurs at the range of 5400 RPM to 6900 RPM with a reduction of 30% in

HC emission. This is the results of as higher HHO gas is being incorporated into the engine, it enhances the fuel oxidation process thus reducing the HC emission.

Hydrocarbons are formed when there are incomplete combustion or unburned fuels. It can react to sunlight and nitrogen oxides to make ozone and cause irritation of the eyes, difficulties in breathing, damages the lungs and other health issues.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

To conclude, the surface roughness of the HHO generator's plate plays a vital role that contributes to the efficiency of the electrolysis process. In this experiment, the fabrication of various HHO plate's surface roughness was a success with three different kind of plates, namely, non-polished plate, one-sided plate, and fully polished plate. The observation of the surface roughness of the plates was also taken with a metallographic microscope and further validated with measurements taken on the roughness of the surface with a roughness tester.

From the experiment, the highest HHO gas produced was 59.79 ml/min when the solution was added with 25 grams of potassium hydroxide was the non-polished plate. In comparison, the fully polished plate had produced HHO gas of only 48.08 ml/min when added with 25 grams of potassium hydroxide. The different in surface roughness of the plate contributes to 24.36% increase in HHO gas produced. This can be concluded that the rougher the surface of the plate, the more the effective surface area for electrolysis process to occur hence contributes to more efficient electrolysis process and higher HHO gas produced under the same condition.

In terms of the performance analysis, when the 150cc motorcycle engine was commissioned with HHO gas into the air intake manifold, the results show a marginal increase in both power and torque of the engine. At engine speed of 8300 RPM, the peak power without the incorporation of HHO gas is 12.67 hp while with the addition of HHO gas is 12.72 hp. The increase in power is a mere 0.4% when commissioned with HHO gas. While in terms of torque, similar pattern is seen when at engine speed of 7700 RPM, the peak torque for baseline is 11.2 Nm whereas the peak torque when added with HHO gas is 11.3 Nm. A marginal increase of only 0.1 Nm or 0.89% increment in terms of torque.

On the other hand, when the engine is commissioned with HHO gas, the results show promising impacts to the emission emitted by the engine. In terms of NOx emission, at engine speed of 7300 RPM, the emission of NOx for baseline reached 262 ppm while when added with HHO gas it only reached 50 ppm. The reduction of NOx emission taken at engine speed of 7300 RPM is 80.92%. For carbon monoxide emission, the results show the reduction of CO emission occurs the highest at lower engine speed of 3300 RPM and below. It was concluded that the CO emission was reduced by 30% to 40% at the engine speed of 2100 RPM to 3300 RPM. The highest reduction of carbon dioxide emission occurs at higher engine speed with an average decrease of 34%. This can be related to the shorter combustion time at higher engine speed where without the addition of HHO gas, more incomplete combustion occurs thus producing higher emission of carbon dioxide. The highest decrease in HC emission occurs at the range of 5400 RPM to 6900 RPM with a reduction of 30% in HC emission. This is the results of as higher HHO gas is being incorporated into the engine, it enhances the fuel oxidation process thus reducing the HC emission.

As for future work, the HHO plates will generate heats after running for a long time. The heat generated will affect the efficiency of the electrolysis process where it will take a longer time to produce HHO gas for 1 scale of the flow meter. This can cause fluctuation in the data collected and may increase the margin of errors in calculating the average. It is recommended that in future research, there would be a time interval before each data for the flowrate of gas produced is collected. Besides, the rubber gasket of the HHO generator should be monitored and maintained as hardened rubber gasket may lead to leaking of gas before reaching the flowmeter. This is due to the HHO generator being frequently changed of the HHO plates by removing the cover. Also, constant unscrewing and screwing back of the HHO generator cover may lead to the rubber gasket being worn out. In addition, the difference in fuel consumption before and after the commissioning of the HHO gas should also be included in the experiment for a more inclusive study.

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