Study on Hydrogen-On-Demand (HOD) System

by

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Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHD FAIZ BIN SOFIAN

ABSTRACT

The topic had been very popular recently was absolutely about price fuel hiking in global market. Not only the country that didn't produced the oil facing this problem, but all around the world, including our country had to faced this problem. Furthermore, we always here the speculations about the decreasing stock of oil from day to day. As example, our country Malaysia, have been forecasted to have the oil under the sea till about 10-15 years more. So, it is be the responsibility to our new generation to find the way and solution to solve this two major crisis in our world now. Many researches have been done by geniuses to find the solution to this problem. Finally they have found new alternative to replace the fossil fuel that we use today. From 1000 thousand experiment that had been conducted, they can proof that Hydrogen can be ultimate substitute for ordinary fossil fuel. The present research shows how can hydrogen will be use to fire up an engine, but the expenses to make it happen is too expensive. This experiment is about mixing hydrogen with fuel to get better car performance, more clean emissions and at the same time will safe you hard earned cash. In this experiment, hydrogen will be produced from electrolysis of water to get the HHO gas and will be mixed with fuel inside the combustion chamber. After performing the test to injection engine, there is small amount of change in power output and torque can be seen. But, there is a lot of improvement to make if we want to use it on everyday life. About the emission, from the gas analyzer test, its shows really good improvement. The results that appear on gas analyzer is the proof that this gas can save the environment and safe to use for alternative fuel. This study also indicates some problem in getting incredible result because there are some limitations on HHO generator itself. However, it can be improve and to see the really good result, experiment should be continue with the recommendations that have been stated.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

The term "alternative fuel" has been used to describe any fuel suggested for use in transportation vehicles other than petroleum or diesel fuel. Alternative transportation fuels today are generally conceded to include ethanol, methanol, natural gas, propane, hydrogen, biodiesel, and electricity (electricity is include even though it is not a fuel). Liquids made from natural gas (primarily diesel fuels, but petroleum are possible as well) are being made in increasing quantities and may soon be marketed as alternative fuels around the world.

In addition to reducing the demand for petroleum fuels, each alternative fuel has some characteristic that gives it an environmental advantage over petroleum fuels. Most are less damaging to the environmental if spilled, and in general, the emissions from alternative fuels are less reactive and toxic. With advent of improved emission control technology, combined with cleaner petroleum fuels such as low-sulfur reformulated gasoline and ultra low-sulfur diesel fuel, petroleum fueled vehicles have emission levels low enough to significantly depreciated most of the emissions benefits of alternative fuels. However, many alternative fuels also produce lower level of green house gases, which petroleum fuels will never be able to match without some sort of remediation of carbon monoxide. Each alternative fuel varies in its level of development and prospects for the future.

1.2 Problem Statement

Fuel price hiking in global market give a big impact to all world population. Although there are not all have owned a vehicle, but it's still give and effect on their live. As we already know, the entire groceries prices are depending on this fossil fuel. This gives more headache for people that really need to use a transportation in their daily life, or people that use transportation as a necessity. Billion ringgit had been spending on research and development to find the best solution to substitute the fossil fuel that we use today. But, it's still not worth it, even though they have found the substitution, the cost to change it also very high. So, we still need to find the way cheaper and can afford by all people.

In the market now, there is one system that not really expensive yet affordable to use on many countries. Hydrogen-On-Demand (HOD) System had been everyday conversation among vehicle user starting on 1996. This system allows people have great saving on their budget on fuel. But, is this system really works? How much its can save? How about its efficiency on normal engine? And is the systems really save to engine and environment? This entire question will be answer once this study has reached it objective.

1.3 Objectives

To analysis the HOD system, effect of HOD system on internal combustion engine, efficiency of HOD system on internal combustion engine, and to prove that this system can really work and it's also the cheaper method to save our money on fuel.

1.4 Significance of study

At the end of this project, it can give some benefits to all people that involve direct or indirectly to complete this project. Hopefully from this project, it can help people to save their pocket money on buying the fuel by using this system. Is this system is really have a good potential; it can be widen to help more people out there with their financial problem. Also, with this project, hope it can be ultimate solution to the current global problem in finding the suitable alternative fuel to substitute the fossil fuel that we using right now.

CHAPTER 2
LITERATURE REVIEW

2.1 Hydrogen Based Vehicle

There have only been a small number of prototype hydrogen vehicles made. Most of these have been experimental vehicles made by car manufacturers. Nearly all of these prototype cars were equipped with internal combustion engines, similar to ones that run on gasoline.

Hydrogen is also used in fuel cells. Fuel cell vehicles turn hydrogen fuel and oxygen into electricity. The electricity then powers an electric motor, just like electricity from batteries powers the motor of an electric vehicle. Fuel cells combine oxygen from the air with hydrogen from the vehicle's fuel tank to produce electricity. When oxygen and hydrogen are combined they give off energy and water (H2O). In fuel cells this is done without any burning (combustion). There are a number of ways that hydrogen can be provided to the fuel cell. One way is simply to put hydrogen gas into the fuel cell, along with air. Hydrogen gas can come from gaseous or liquid hydrogen stored on the vehicle. To carry gaseous hydrogen on a vehicle, it must be compressed. When compressed (usually to a pressure of about 3000 pounds per square inch), it must be stored in special high-pressure containers. This is similar to the way compressed natural gas is stored on natural gas-fueled vehicles.

Hydrogen has many characteristic that make it the "ultimate" alternative fuel to fossil energy fuels. Hydrogen can be combusted directly in internal combustion engines, or it can be used in fuel cells to produce electricity with high efficiency (30-50% over the typical load range). All the major auto manufacturers are working on fuel call vehicles, and hydrogen is the preferred fuel for them. When hydrogen is oxidized in fuel cells, the only emission is water vapor. When combusted in an internal combustion engine, some oxides of nitrogen and peroxides may be produced, depending on the calibration of the fuel system and configuration of the engine. None of the toxic emissions typical of petroleum fuels are present. Therefore, the use of hydrogen as a transportation vehicle fuel would result in few or no emissions that would contribute to degraded air quality (i.e., ozone formation). The relative effect hydrogen would have on greenhouse gas emissions is dependent on how the hydrogen is produced.

2.2 Physical and Chemical Characteristic of Hydrogen

Hydrogen as a liquid has about 27% of the energy per liter of gasoline, and about 23% of the energy per liter of diesel fuel. As a compressed gas at 5000 psi, hydrogen has only about 8% the energy if gasoline, hydrogen will need at least 4 times the fuel storage volume if liquid stored as a liquid, and 12.5 times the storage volume if stored as compressed gas. But this understates the practical difference between hydrogen storage and gasoline storage. High-pressure hydrogen tanks cannot be shaped to conform with the available space in tanks have to account for insulation volume in addition to being restricted in the shapes they can have (i.e., cylinders and spheres).

Hydrogen has the widest flammability range of a fuels-4-75 volume % in air. This wide flammability range has significant implications for hydrogen safety. Hydrogen also tends to diffuse more readily than natural gas, so leaks of hydrogen will diffuse rapidly within a space and will be in the flammable range for a long time in comparison to other fuels, Hydrogen also burns without a visible flame in direct sunlight, which is an additional safety concern.

Below is the table of comparison of properties between hydrogen, gasoline and diesel fuel.

Table 2.1: Hydrogen Properties Compared to Those Gasoline and Diesel Fuel

Fuel Property	Hydrogen	Gasoline	No.2 Diesel Fuel
Formula	H_2	C_4 to C_{12}	C_8 to C_{25}
Molecular Weight	2.02	100-105	200(approx.)
Composition, Weight % Carbon Hydrogen Oxygen (oxygenated or reformulated gasoline only)	 0 100 0	 85-88 12-15 0-4	 84-87 13-16 0
Density, kg/L	0.0013(g), 0.07(l)	0.69-0.79	0.81-0.89
Specific Gravity	0.07(g), 0.07(l)	0.69-0.79	0.81-0.89
Boiling Point, °C	-253	27-225	188-343
Latent Heat of Vaporization, kJ/kg	448	349	233
Lower heating Value, 1000 kJ/L	8.4	30-33	35-37
Flammability Limits Vol% Lower Higher	 4[d] 75	 1.4 7.6	 1.0 6.0
Stoichiometric Air-fuel Ratio, Weight	34.3	14.7	14.7
Flame Visibility	Invisible in direct sunlight	Visible in all conditions	Visible in all conditions

2.3 Hydrogen on Demand System

However there is one method, that still use hydrogen as alternative fuel, but not all depend on hydrogen only, it is also will mix up with gasoline or diesel fuel to complete the combustion in internal combustion engine. By using this method, they claim that when hydrogen was compressed to an internal combustion engine it is releases more energy than ethanol-based mixes, maintaining the overall power of the car, completely burns the fuel which gives cleaner emissions, raises the octane level of the fuel, preventing knocking, making the engine quieter, lowers overall engine temperature slightly and requires the engine to use less gas per cycle so mileage gains as low as 20% to as high as 70% on the average due to less fuel required by the engine.

It is also generate hydrogen only on demand and is therefore safe. When no electricity is routed through the HOD system, no reaction is generated. No hydrogen is in storage in this system but is kept in medium, which is basically water. Parts are sourced from everyday parts found in hardware shops and basic electronics stores. Total cost for a basic unit can range between RM 200 to over RM 600.

2.4 Personal Experience using Water 4 Gas by Craig Wilson

In his blog called "Water 4 Gas Test" this author have list the chronology of what he does to test the truth of this system, either its working or not. He started the project on 15/6/08 and takes about 1 month to get all complete result after testing.

The author implemented the system on his wife's car, Toyota Camry, 1997, four cylinders 2.2 liter, automatic power house with almost 240,000 KM on the meter. Before installing the system, he has made some servicing on that car. He have changed the spark plugs, replace oil and filter and also clean the throttle body so when he start off, he will start with clean slate starting. The author also monitored the tire pressures on a weekly basis to ensure that the result will be get are as accurate as possible. He also will use the air-conditioning occasionally because there will turn up into winter. Most of type of driving that he do is city type driving and also couple of highway runs of equal distance to accurately compare the fuel usage. For his first run without the system, he used 55.90 Liters of petrol and the odometer reading is 237,158 KM. But for benchmarking data can be refer from table 2.2.1.1. The author took the benchmarking data that propose by the Australian's Finance Minister.

Table 2.2: Benchmarking data

Distance Travel (KM)	Fuel Used (L)	Average Consumption (L/KM)
423.5 KM	55.90 L	13.19 L/100 KM

On that article, he stated that he takes about a week to get all the raw material and all the tools to ready the system. After that, he wait for first time fuel light as his guide for refilling and assuming that his car gauge are reasonably accurate to complete the test.

(a)HOD system installed

(b) 97' Toyota Camry

Figure 2.1: Car that Craig Wilson use for experiment

2.4.1 First Test Result of Personal Experience Using HOD System by Craig Wilson

For the first star-up and first drive he found that there are certainly noticeable difference in the way the car behaved. The first thing that the author noticed was the improvement in the idle state, the engine felt smoother and slight variances in the tachometer at idle had all but disappeared. He also noticed that the exhaust smell has changed, not much better but definitely different.

In same the weather and condition in his place before, he did find that the engine felt stronger throughout the rev range compared to same condition without the system installed. Typically the car tends to flatten out a bit after about 5,500 RPM and this trait has not changed much with the system. He actually starts the test after second fill-up and reset the trip meter. The car still feels like it is pulling stronger and idle quality has improved. Details for second fill-up are 55.90 L at 237,960 KM, and the test has begun.

After about a week, finally he gets the meter reading on mileage. On meter, 462 KM from 55.90 L of fuel. The benchmark sets without the system is 423 KM with 55.90 L fuel. In increase about only 39 KM without changing the habits of driving. So for summarize the result, can be refer on table 2.3.

Table 2.3: Summarize result

	Distance Travel (KM)	Fuel Used (L)	Average Consumption (L/KM)
Benchmarking	423.5 KM	55.90 L	13.19 L/100 KM
Result	462.2 KM	55.90 L	12.09 L/100 KM

So, from the result, the author can see there is only slight changed of fuel consumption after installed the system. From 13.19 L/100 KM to 12.09 L/ 100 KM equals to 9.22% of improvement. So, after a few study and research, he has made some conclusion and recommendations.

Figure 2.2: Reading on meter

2.4.2 Recommendation by Craig Wilson on HOD System

So, for the recommendation, he recommends to adjust the air-fuel ratio mixture by using an adjustable electronic ‘pot’ to control the signal from the oxygen sensor to the computer. He will use a stoichiometer to observe this thing. He also recommends to use more than one system to get better result is saving fuel. HHO system may work better on carburetor engine infect the fuel injection engine as stated on the manual. To use it on injection engine, this system need to modify the mixture input to computer.

Other than setting the mixture control, the author also will do some modifications on the system itself by putting the ‘bubbler’. The function of this ‘bubbler’ is to add more safety by adding merely tube of around 25mm in diameter and about 20 cm long and half filled with water. The idea is that the tube running from to hydrolyser is attached to the bottom of the tube, the outlets to engine are in the top cap as the HHO gas is produced it bubbles up through the water and through the hoses to the engine. Should we have the backfire, which is possible when trying to lean the mixture out, any flames will stopped by the water in the bubbler before getting any further.

2.5 Variables Affecting Performance Characteristic

There are several variables that can be changed or manipulated. Before any variables need to be apply to improve the performance, engine performance curves need to be study first. The shapes of these curves or the engine performance are determined by the regulation of many design and operating variables. Some of the important variables will be briefly discussed and summarized in this section.

2.5.1 Combustion rate and spark timing

The spark should be timed and the combustion rate controlled such that maximum pressure occurs as close to the beginning of the power stroke as possible, consistent with as smooth running engine. As a general rule, the spark timing and combustion rate are regulated in such a way that approximately one half of the total pressure rise due to combustion has occurred as the piston reaches TDC on the compression stroke.

2.5.2 Air-Fuel Ratio

This ratio must be set to fulfill engine requirements. Consistent with these requirements, however, it is usually set as close as possible to the best economy proportions during normal cruising speeds, and as close possible to the best power proportions when maximum performance is required**.**

2.5.3 Compression Ratio

An increase in compression ration increases the thermal efficiency, and is, therefore, generally advantageous. This compression ratio in most SI engines in limited by knock, and the use of economically feasible antiknock quality fuels. Increasing compression ratio also increases the friction of the engine, particularly between piston rings and the cylinder walls, and there is a point at which further increases in compression ratio would not be profitable, though this point appears to be rather higher.

2.5.4 Engine Speed

At low speeds, a greater length of time is available for heat transfer to the cylinder walls and therefore a greater proportion of heat loss occurs. Up to a certain point, higher speeds produce greater air consumption and therefore greater speed. Higher speeds however are accompanied by rapidly increasing and by greater inertia in the moving parts. Consequently, the engine speed range must be a compromise, although most present day designs appear to favors the higher speeds.

2.5.5 Mass of Inducted Charge

The greater the mass of the change inducted, the higher power produced. For given engine, the geometry is fixed, and it is desirable to induct a charge to a maximum possible density giving the highest volumetric efficiency.

2.5.6 Heat Losses

It should be noted that the large proportion of the available energy is lost in a non-usable form, i.e., heat losses. Any method which can be employed to prevent the excessive heat loss and cause this energy to leave the engine is a usable form will tend to increase engine performance. Higher coolant temperatures, for instances, provide a sampler temperature gradient around combustion chamber walls and a reduction in heat loss, but are limited by the possibility of damage to engine parts.

2.6 Exhaust Gas Emissions

The expected result for emissions of alternative fuel is a reduction in pollutant emission. The emission of pollutant from combustion processes can be reduces by four different methods:

1. Energy efficiency improvements
2. Refinements and modifications to the combustion process
3. Flue gas treatment
4. Switching to cleaner fuels or alternative energy source.

Thus this project, the method to reduce pollutant emissions is using cleaner alternative fuels. Before that, the typical pollutant gas components should be identified as below:

a) Carbon dioxide (CO_2)

Although this gas is non-poisonous, it may still be considered a problem, especially if it is produced in large enough quantities to displace oxygen in the working environment

b) Carbon Monoxide (CO)

CO is the result of the incomplete combustion of the fuel, caused by localized insufficient of oxygen (rich fuel/air ratio). Quenching of the reaction by cold combustion walls also increases the CO levels. (Example: cold engine operating temperatures) CO gas is colourless, odourless, and tasteless gas. Inhalation of little as 0.3% by volume can cause death with 30 minutes. For this reason, it is important never to allow the engine run in enclosed spaces such as a close garage without good ventilation. Increase CO concentrations may be result of poor mixture formation caused by detective injection system, injection with defective spray characteristic, or engine over fuelling.

c) Oxide of nitrogen (NO_x)

The formation of NO_x is dependent on the temperature during the combustion process, the concentration of the components nitrogen (N_2) and oxygen (O_2) and the time available for them to react with each other. NO and NO_2 are generally lumped together and referred to as oxides of nitrogen (NO_x). A rise in the combustion temperature increases the NO concentration in the exhaust gas. In diesel engine, the combustion process forms only NO and small portion of which oxidized to NO_2 at lower temperatures and in presences of O_2. The sum of NO and NO_2 is called NO_x. These gases belong to two different classes. Nitrogen monoxide (NO) is a colourless, odourless and tasteless gas that is rapidly converted into nitrogen dioxide (NO_2) in the presence of oxygen (O_2). Advanced injection timing can cause an increase of NO in the exhaust gas. Measure which decrease the NO concentrations, such as low compression ratio or retarded injection timing, also tend to decrease the efficiency of the combustion process this can result in increased fuel consumption and higher CO and HC concentration in the exhaust.

d) Hydrocarbon (HC)

HC in exhaust gases is usually from very small quantities of unburned diesel fuel and engine lubricating oil. Since the measurement of concentration of different hydrocarbon involves the use of sophisticated instrumentation, only total HC is usually measured and reported. In the presence of nitrogen oxide and sunlight, hydrocarbons are cancer-causing. Incomplete combustion in a diesel engine produces unburned hydrocarbons. Increased HC level in the exhaust gas are found when a diesel engine suffers from high oil consumption, a defective injection system, rich fuel/air ratio, or quenching of the combustion process in the proximity of the cold combustion chamber walls.

e) Oxides of Sulfur (SO_x)

The Sox formation is caused by the oxidation of the sulfur contained in the fuel with the O_2 with the available in the combustion air. The SO_x concentrations depend on the sulfur content of the diesel fuel and the fuel consumption of the engine. SO_x reduction in the diesel exhaust gas can only be achieved through the use of low sulfur fuels.

f) Particulate matter (PM)

These include all substances (with the exception of water) which under normal condition are present as small solid or liquid particles in exhaust gases. PM is usually defined as “any material, other than water in the exhaust id a diesel engine which can be filtered after dilution with ambient air”. These particulates normally consist of mixture of carbon (soot), hydrocarbons and sulfuric acid. Therefore we can assume that conditions, which affect the formation of soot, hydrocarbons and oxides sulfur, will affect the particulates emissions.

2.7 Internal Combustions Engines

Appropriately modified, a hydrogen-powered car with an ICE does not differ from conventional gasoline or diesel car in its driving and power properties or in its acoustics.

Some properties of hydrogen make engine modifications necessary. Low ignition energy and high flame speed can cause self-ignition during the mixture preparation or flame flashback. The octane number of hydrogen is much lower than that of gasoline. However, the wide ignition range allows burning of lean mixtures and gives a large control range.

Various techniques are used to prepare the feed mixture for the combustion chamber. With external mixing a homogeneous hydrogen – air mixture is introduced. Uncontrolled pre ignition or flash-back into the intake manifold is prevented by adding ballast, preferentially water, and by timed individual port injection of hydrogen close to the cylinder intake. Internal mixture formation is achieved by direct injection into the combustion chamber. The necessary supply pressure must be at least 1.5 MPa, or up to, depending on the time of injection, more than 10 MPa. This only possible by using piston pumps for liquid hydrogen.

Attainable specific charge heating values (energy content per cylinder loading) are compared in Table 2.4, under various operating condition. Revolutions per minute (rpm) and effective efficiencies are comparable to the gasoline motor. Because of the lower amounts of air possible and the lower heating value of mixture, external mixture formation with water injection gives power rating comparable to that of diesel motors, whereas with the internal mixture ca. 40 kW/L cylinder volumes were attained.

Table 2.4: Specific charge heating value of hydrogen – air mixtures in combustions engines compared with gasoline

Operating conditions	**Maximum of spec. charge HV, $H_{spec.max}$**		**Maximum of efficiency, η_{emax}**		**Maximum of excess air, φ_{min}**	
	φ	kJ/L	φ	kJ/L	φ	kJ/L
Gasoline	1	37.7	1.1	34.4	0.83	31.6
Hydrogen (external mixture formation)	1	31.9	0.4	15.5	0.2	8.3
Hydrogen (internal mixture formation)	1	45.3	0.4	18.1	0.2	9

Hydrogen-powered engines emit only water, nitrous oxides (NO_x), and due to combustion of small amounts of engine lubricants minor traces of hydrocarbons (C_xH_y) and carbon monoxide (CO).

Combustion is a chemical reaction in which an oxidant reacts rapidly with a fuel to liberate stored energy as thermal energy, generally in the form of high-temperature gasses. Small amount of electromagnetic energy (light), electric energy (free ions and electrons), and mechanical energy (noise) are also produced during combustion. Expect in special applications, the oxidant for combustion is oxygen in the air.

Conventional hydrocarbons fuels contain primarily hydrogen and carbon, in elemental from or in various compounds. Their complete combustion produces mainly carbon dioxide (CO_2) and water (H_2O); however, small amount of sulfur, which is oxidized to sulfur dioxide (SO_2) or sulfur trioxide (SO_3) during combustion, and noncombustible sub-stances such as mineral matter (ash), water and inert gases.

Flue gas is product of complete or incomplete combustion and includes excess air (if present), but not dilution air. Fuel combustion rate depends on:

1. The rate of the chemical reaction of the combustible fuel constituents with oxygen
2. The rate at which oxygen is supplied to the fuel (the mixing of air and fuel).
3. The temperature in the combustion region.

The reaction rate is fixed by fuel selection. Increasing the mixing rate or temperature increases the combustion rate. With the Combustion Laboratory Unit, the mixing rate for stoichiometric combustion can be analyzed. Thus, a specific mixing fuel for better economic fuel consumption can be determined.

With complete combustion of hydrocarbon fuels, all hydrogen and carbon in the fuel are oxidized to H_2O and CO_2. Generally, for complete combustion, excess oxygen or excess air must be supplied beyond the amount theoretically required to oxidize the fuel. Excess air is usually expressed as a percentage of the required to completely oxidize the fuel.

In stoichiometric combustion of hydrocarbon fuel, fuel is reacted with the exact amount of oxygen required to oxidize all carbon, hydrogen and sulfur in the fuel to CO_2, H_2O, and SO_2. Therefore, exhaust gas from stoichiometric combustion theoretically contains no incompletely oxidized fuel constituents and no unreacted oxygen (i.e., no carbon monoxide and no excess air or oxygen). The percentage of CO_2 contained in products of stoichiometric CO_2, ultimate CO_2, or maximum theoretical percentage of CO_2.

Stoichiometric combustion is seldom realized in practice because of imperfect mixing and finite reaction rates. In actual application, however, it is impossible to get perfect mixing of fuel and air. Thus additional air, termed excess air, is required to burn the fuel safely and completely. The more refined the fuel, the less excess air is needed. Minimum quantities of excess air are required to ensure good combustion, too much excess air leads to lowered thermal efficiency as larger quantities of heated flue gases are produced and discharged to the atmosphere.

Incomplete combustion occurs when a fuel element is not completely oxidized during combustion. For example, a hydrocarbon may not completely oxidize to carbon dioxide wand water, but may from partially oxidized compounds, such as carbon monoxide, oxygen and NO_x. Conditions that promote incomplete combustion include:

1. Insufficient air and fuel mixing (causing local fuel-rich and fuel-lean zones).
2. Insufficient air supply to the flame (providing less than the required quantity of oxygen)
3. Insufficient reactant residence time in the flame (preventing completion of combustion reactions).
4. Flames impingement on a cold surface (quenching combustion reactions)
5. Flame temperature that is too low (slowing combustion reactions). Incomplete combustion uses fuel inefficiently, can be hazardous because of carbon monoxide production, and contribute to air pollution.

The usual combustion process is accompanied by the bright glow or flame, a characteristic of fast, high temperature oxidation. The flame front or surface is an area of very rapid chemical reaction and is a boundary between burned and unburned gas that continually moves towards the unburned gas. The thickness of the flame front (or combustion wave) may range from very thin (1/10 mm) to indefinite thickness, depending on the local conditions. The more rapid the combustion, the thinner the flame front, and in the usual burned flame, ignition and combustion occur almost simultaneously and inseparably. Propagation of flame is generally a thermal process in that flame must transfer heat to the unburned gas to cause it to ignite.

CHAPTER 3
THEORY

3.1 Production Hydrogen with Electrolysis

Electrolysis has been used for approximately 100 years for the production of hydrogen. The first large installation was by Norsk Hydro in 1927 in Norway. Futher plants were erected by Comico in Trail, British Columbia, Canada in 1940 and, from 1945 onwards, other plants with capacities up to 33000m3 (STP)/h of hydrogen [50-500m3 (STP)/h] are often used by the industry because they are simple to operate. Moderate power costs are an additional incentive. Annually 1-4% of hydrogen is produced by electrolysis.

3.2 Electrochemical Principles

If potential is applied to the electrodes of and electrolysis call filled with a suitable aqueous electrolyte, the following reaction occurs at the electrodes:

Cathode

$$2H_2O(l) + 2e^- \rightarrow H_2\ (g) + 2OH^-\ (aq)$$

Anode

$$2OH^-\ (aq) \rightarrow 1/2O_2\ (g) + H_2O\ (l) + 2e^-$$

Cell reaction:

$$H_2O\ (l) \rightarrow H_2\ (g) + 1/2\ O_2\ (g)$$

*Where 1 denotes liquid, g gaseos and aq dissolved in water.

Pure water is not suitable for electrolyte because of its very low conductivity. Therefore, aqueous solutions of potassium pr sodium hydroxide, sodium chloride, hydrochloric acid, etc. are used. Depending on the electrolyte and the material of the electrolytes the electrodes the reaction at the anode may lead to other products, in particular to sodium hydroxide and chlorine.

The change in enthalpy for the electrochemical decomposition of water is

$$\Delta H = \Delta G + T\Delta S = -nFE + nFT.\left(\frac{\partial E}{\partial T}\right)_p$$

Where H is the enthalpy, G the Gibbs free energy , S the entropy, T the temperature, n the number of electrons transferred per formula conversion, F the Faraday constant and E the electrochemical potential.

The thermodynamic standard data at p = 101.3 kPa and T = 298.15 K are:

- Reaction enthalpy: $\Delta H^0{}_{298}K = 286 kJ/mol$
- Reaction entropy: $\Delta S^o{}_{298}K = 163 j/mol/K$
- Gibbs free energy of reaction: $\Delta G^0{}_{298}K = 237 kJ/mol$

The value of the Faraday constant is:

F = 96.485 A s/kmol

Using these data the required electrical energy becomes:

$$W = \Delta G = F \times n \times E_{rev}$$

Where E_{rev} is the ideal (reversible) decomposition potential. Under standard conditions this amounts to:

$$E_{rev} \frac{\Delta G}{n.F} = 1.228V$$

Because the irreversible process on the electrodes and the resistance of the electrolyte, the actual decomposition potential is always higher than the ideal value.

According to the eq. $\Delta H = \Delta G + T\Delta S = -nFE + nFT.\left(\frac{\partial E}{\partial T}\right)_p$ ΔG, is smaller than the reaction enthalpy, ΔH, by the amount $T\Delta S$. In the ideal case, operation of the cell requires an amount of electrical energy, $W = \Delta G$, and the addition of heat, $Q = T\Delta S$. If both amounts of energy are to be supplied in the electrical form, the potential under standard condition is increased by the thermal potential ΔE_Q.

$$\Delta E_Q = \frac{T\Delta S}{n.F} = 0.252 \text{ V}$$

Thus, the theoretical minimum decomposition potential under standard conditions is:

$E_{th} = 1.408$ V

The potential actually required is the sum of the following contributions:

$U = E_1 + E_2 + E_3 + E_4$

Where U is the cell voltage (V), E1 the theoretical call voltage (Erev) (V), E2, E3, the anodic and cathodic overvoltages (V) at the phase boundary electrolyte – electrode, respectively, and E4 is the voltage drop (V), due to electrical resistance of the electrolyte system.

The over voltages E2, and E3, can be influences by suitable choice of the electrode materials and their surfaces conditions. The voltage drop in the electrolyte, E4, depends on:

1) the conductivity of the electrolyte
2) the permeability of the cell diaphragms
3) the distance of the electrodes from one another
4) the current density

The efficiency of the electrolysis is related to the minimum voltage according to $\Delta H = \Delta G + T\Delta S = -nFE + nFT.\left(\frac{\partial E}{\partial T}\right)_p$:

$$\eta = \frac{E + \frac{T\Delta S}{nF}}{U}$$

Under standard conditions: $\eta = \frac{1.48}{U}\frac{V}{V}$

3.3 Efficiency and Compression

Efficiency is a very important factor in judging engine performance. It can be classified as:

- Thermal efficiency ηth (based on idealized process);
- Indicated efficiency ηi (based on the values measured in the cylinder)
- Effective efficiency ηe (based on the values measured at the crankshaft)

If the efficiency is known, specific fuel consumption (b) of engine can be computed as follow:

Since the value obtained from multiplication of efficiency η by the lower heating value H_u stands for work per amount of fuel put in, and since specific fuel consumption (b) is defined as the amount of fuel put in per unit of work, specific fuel consumption (b) can be expressed as:

$$b = \frac{1}{\eta . Hu}$$

Constant-volume, constant-pressure, and limited-pressure cycles are calculated as a functional of the compression ratio ε – which represents a potential means of substantially influencing efficiency.

Apparently that efficiency generally increases with increasing compression rations. Further, starting out from the limited-pressure cycle, efficiency increases towards the constant-volume cycle and decreases toward the constant-pressure cycle.

Compression

The difference between the maximum piston displacement V_h and the compression volume V_c is the compression ration

$$\varepsilon = (Vh + Vc) / Vc$$

The engine compression ration is a vital factor in determining:

- Torque generation
- Power generation
- Fuel economy
- Emissions of harmful pollutants

The gasoline-engine's compression ratio ε varies according to design configuration and selected form of fuel injection (manifold or direct injection ε = 7….13). Extreme compression rations of the kind employed in diesel powerplants (ε = 14…24) are not suitable for use in gasoline engines. Because the knock resistance of the fuel is limited, the extreme compression ratios must be avoided in order to prevent spontaneous and uncontrolled detonation of the air/fuel mixture. The resulting knock can damage the engine.

3.4 Air-Fuel Ratio

Complete combustion of the air/fuel mixture relies on a stoichiometric mixture ratio. A stoichiometric ratio is defined as 14.7 kg of air for 1 kg of fuel, that is, a 14.7 to 1 mixture ratio.

The air/fuel ratio λ (lambda) indicates the extent to which the instantaneous monitored air/fuel ratio deviates from the theoretical ideal:

$$\lambda = \frac{\text{induction air mass}}{\text{Theoretical air requirement}}$$

The lambda factor for a stoichiometric ratio is λ 1.0. λ is also referred to as the excess-air factor.

Richer fuel mixtures result in λ figures of less than 1. Leaning out the fuel produces mixtures with excess air: λ than exceeds1. Beyond certain point the mixtures encounters the lean-burn limit, beyond which ignition is longer possible. The excess-air-factor has a decisive effect on the specific fuel consumption and untreated pollutant emissions.

CHAPTER 4
METHODOLOGY

4.1 Overview

This research can be categorised into two main sections. The first part is on building the HHO generator and the second part is on the experiment to prove the capability of the generator regarding variables that have been stated on the objective of this study. For the second part, because of the time consuming, the test have only can be done on injection engine only.

4.2 Gantt Chart and Project Flow

To ensure the generator that will be build is within the budget and its safe to be use in the experiment on part 2, some calculation needs to be tackle down to determine the actual hydrogen will be produce for certain measurement of the generator with vary with time. To make the calculation possible, we need to consider some design parameter to solve the calculation. The other way to prove the calculation that has been done is by using experimental based result. But, this type of method only can be done after all the work in building the generator have been done.

In designing the generator, deep research need to be consider. All method in data gathering has been used to get all possible data in performing this project. Somehow, there is still need to be referred to supervisor to make sure the formulae that will be use in the calculation is validate for the experiment. Besides that, to construct the diagram to build the generator, we need to consider more than one design. This is to make sure; the generator can really work and also must be within the budget. Shown in Figure 4.1 and Figure 4.2 is the Gantt chart for the project planning and progress.

Table 4.1: Semester 1 Gantt Chart

No	Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Abstract, Problem statement, Objective and scope writing														
3	Literature review and theory about hydrogen writing														
4	Submission of Preliminary Report														
5	Literature review and theory about hydrogen engine, fuel cell and HOD system writing														
6	Collecting information on methodology of experiment														
7	Literature review and theory about electrolysis writing														
8	Method and Procedure Planning														
9	Submission of Progress Report														
10	Seminar														
11	Literature review and theory about internal combustion engine, emissions, and electrolyzer design writing														
12	Literature review about equations and calculation involve in experiment writing														
13	Collecting material for hydrogen generator														
14	Submission of Interim Report														
15	Slide preparation for oral presentation														
16	Oral presentation														

Table 4.2: Semester 2 Gantt Chart

No	**Activities / Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	HOD System Preparation														
2	Submission of Progress Report 1														
3	Test on engine bed														
4	Submission of Preliminary Report 2														
5	Seminar (compulsory)														
6	Results Gathering & Discussion														
7	Poster Exhibition														
8	Submission of Dissertation (softbound)														
9	Oral Presentation														
10	Submission of Dissertation (hardbound)														

Shown in Figure 3.3 is the flowchart of project planned for Semesters 1 & 2. The information is obtained from internet and previous research by other institutes. The design of the generator should be finish early before the experiment can be done. So, for the first of the FYP, the design and fabrication of HHO generator will be done and for the second half of the FYP, some experiment and testing will be perform to gather all the result and see whether it meet its objective or not. Figure 3.3 will show what will be done during both half of the FYP.

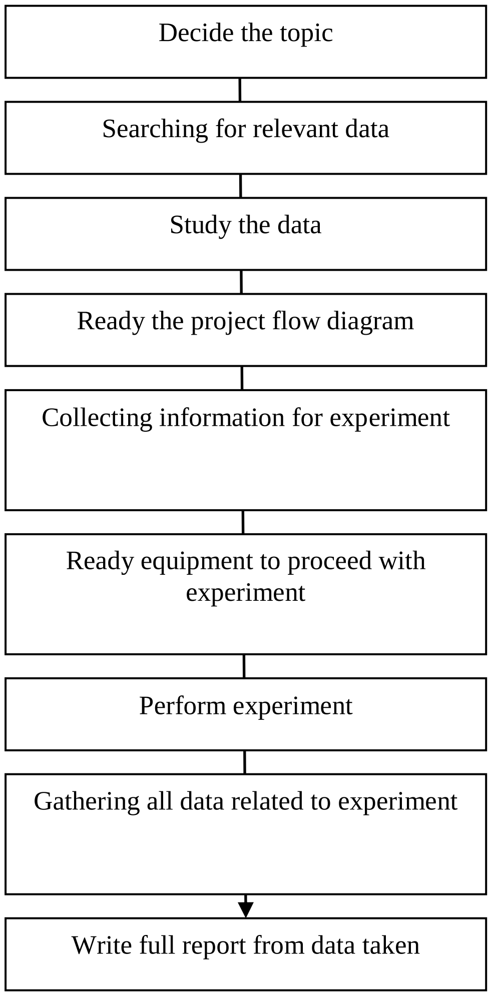


Figure 4.1: Project flow planning for both semesters

4.3 Designing HHO Generator

An electrolyzer produces hydrogen (and oxygen) from water when supplied with electrical current. The electrolyzer used in this experiment system utilizes a proton exchange membrane (PEM) as the solid polymer electrolyte between anode and cathode. The membrane has the characteristic of being impermeable to water, oxygen, and hydrogen gas. Furthermore, the membrane passes currently only in the form of protons. In the present system, the PEM electrolyzer is designed such that one face the membrane is on contact with and oxidation catalyst. Water supplied to the anode from the water reservoir is dissociated and the resulting oxygen gas is allowed to escape from water reservoir. An external power source remove the electron from the hydrogen atoms, and the resulting proton passes through the proton exchange membrane to the cathode where an electrons is provide to form in hydrogen. The hydrogen atom (H^+) combine to form molecules (H_2), resulting in the formation of free hydrogen gas as the cathode.

As a result of the formation of free hydrogen gas at the cathode, the electrolyzer has the capability of generating and delivering the gas at pressures far above ambient. In addition, no moving parts are required for the generation and designed electrolyzer is capable of generating a high reservoirs.

4.4 HHO Generator Using Hydrolisis

The design of the generator still under study. Basically, the generator fir this experiment is using the hardware that can get easily from the workshop in our place. This is because to meet the budget that has been spare for every FYP student. The design of this generator consists of:

1) 4" PVC drain pipe schedule 80
2) Standard end cap for 4" PVC pipe
3) 3/8" Stainless-steel flexible tubing
4) Epoxy and silicon sealant
5) Fitting and drain valve
6) Tubing to attach to intake manifold

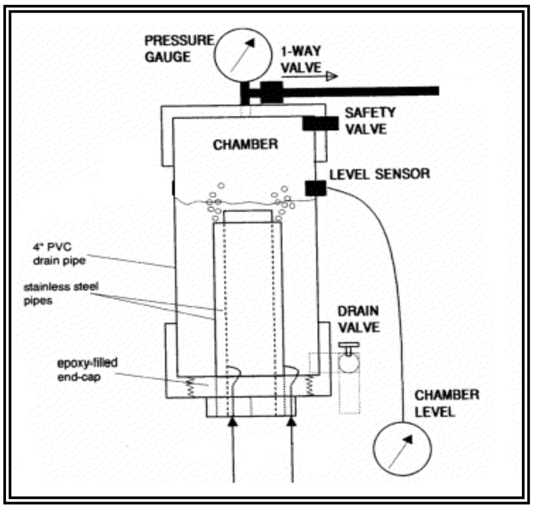


Figure 4.2: Schematic diagram of hydrogen generator [4]

The design is must comply with certain standard to make sure the safety of the generator. As example, the casing must be made from pipe schedule 80 to prevent the generator form blowing out and to hold the pressure. The generator also should be completed with safety valve. For fitting like pressure gauge, level sensor is needed to make the observation of this project much easier.

The design for electrode and how it will connect is still under study. The principle is to connect the generator to 12V car battery and the outlet of the generator will be connecting to intake manifold. For the time being, engine test bed is the suggested engine to run this experiment.

4.5 Engine Test Bed Specifications

After doing some researching, finally the ideal engine that suitable for the experiment is FORD MVH 418 injection engine. However, there are still several modification needs to be done before proceed to the experiment. One major thing that still needs to figure out is how to measure the quantity of the hydrogen that will be use in combustion. One of the solutions is to put flow meter at the tube before the gases enter the intake manifold.

Another problem need to be considered is making a hole on the intake manifold hose. Luckily, we have come out with solution to replace the intake manifold with the already modified new intake manifold. This hose can be purchase at any spare part shop.

Below are the specifications of the engine that will be use in this experiment.

Table 4.3: Engine Specification

Type	Spark ignition engine
Stroke	4
No. of Cylinder	4
Cylinder Bore	80.6 mm
Cylinder Stroke	88.0 mm
Displacement	1796 cc
Compression Ratio	10 : 1
Fuel system	Direct injection
Max. Power	77 kW at 5500 rpm
Max. Torque	153 Nm at 4000 rpm

There are several more alternative to do the experiment. If this engine is too complicated to precede the experiment, single cylinder engine still can be use. Motorcycle engine also one of another alternative choice. But, there are still need to be modified to run the experiment

(a) Back view

(b) Front view

(c) Air filter

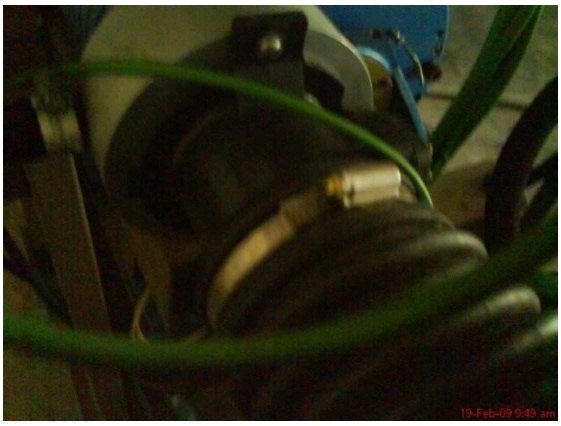
(d) Exhaust

(e) Dynamometer

(f) Left view

(h) Intake manifold

(i) Right view



(j) Intake Manifold hose

(k) Oil control panel

Figure 4.3: Picture of the engine test bed

Above are some pictures of the engine that will be use in this experiment. There is still some modification need to be done to precede the experiment. The engine test bed usages have been schedule on week 6 to give a chance to another student to use it for thermodynamics 2 laboratory sessions. The engine test bed is located at Old block USM, Block N. The person in charge of the laboratory is Mr. Fahmi.

4.6 Methodology of the Experiment of Engine Test Bed

Incorrectly installing or incorrectly using generator may result in serious damage or body injury. HHO is combustible, after the engine started. Yet the generator system does NOT store hydrogen when installed properly, so there is no fire hazard due to hydrogen storage. So again, don't let people who don't understand the system intimidate you or tell you about non-existent hazards.

Below is the diagram how the genitor will be connecting:

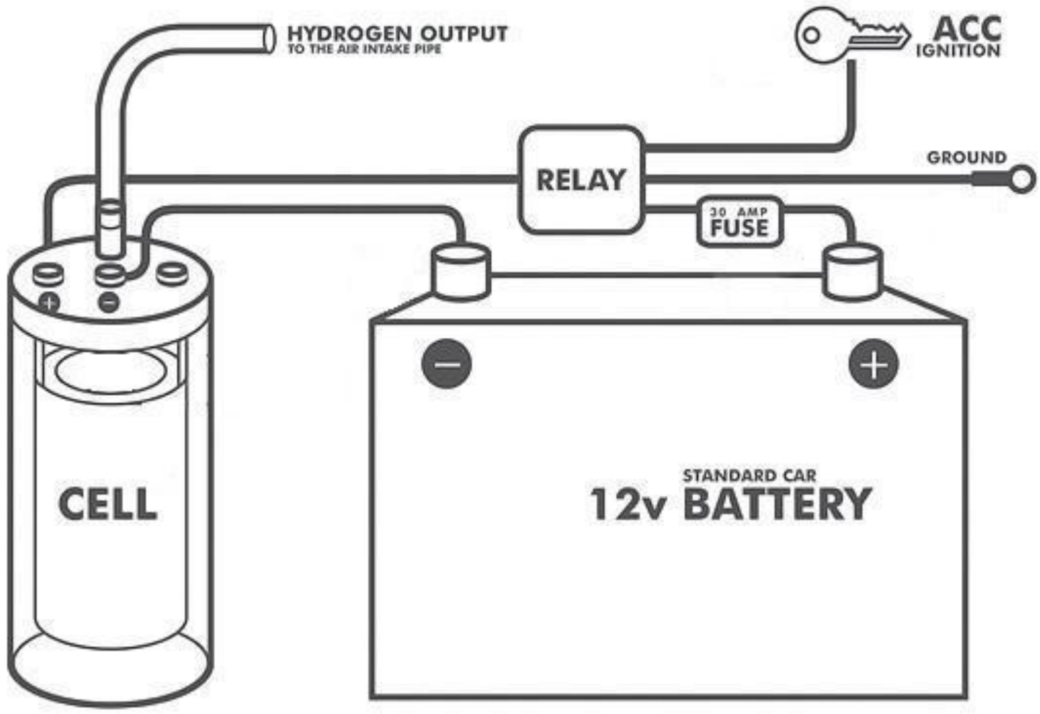


Figure 4.4: Connection diagram [4]

4.6.1 Step to install the generator on the engine

1. Mount the HHO Water fuel device in the engine compartment. It should be mounted flat and level.
2. Position the device so that it can easily be accessed and can be conveniently removed and filled with water, or cleaned, serviced or inspected.
3. ¼ tubing will be use to connect the outlet of generator to the intake manifold.
4. Shut-off valve for ¼ tubing will be use at the end of tube to control the hydrogen flow from the generator. This shut-off valve also will be use as connector from the tubing to the intake manifold hose.
5. Gun glue or epoxy will be use to seal hole at the intake manifold. This is to make sure no leaking will occur during experiment because of the connection at the shut-off valve.
6. Wire will be use to connect the generator to the power source. In this experiment, we will use the standard 12 volts car battery.

7. Negative terminal from the generator will be connecting to negative terminal of the car battery. Make sure the terminal is correct to prevent any accident.
8. Positive terminal from the generator will be connection g to the relay coil. From the relay coil, the connection will be dividing to three more connection. One will go to ignition switch, one to grounding and one more to the positive of the car battery. Fuse 30 amp will be place before connection to the car battery. This is to make sure; there is no current overloading while doing this experiment.

4.6.2 Precautions step need to be taken before engine will be fire up

1. Do not shorten vacuum line between the engine intake and the generator. Keep the line (hose) at least 4 ft long. This length must be kept to enhance safety and prevent damage to the device. Work outside, no smoking; make sure the engine is not hot. Wear goggles and gloves.
2. Make sure all connection between intake manifold and generator will be completely seal. This is to makes sure, no hydrogen leaking while performing the experiment. Hydrogen is dangerous gas, it will explode is the gas expose directly to the fire. Use epoxy gun glue to seal all hole that may cause any leaking.
3. The cap of the generator also needs to seal tightly to make sure no leaking from the generator. White tape can be considered to use to seal the cap of the generator. Put the cap tighter to prevent any leak. If possible add another safety valve and locking system to prevent the cap from being opened while conducting the experiment. Safety pressure valve is a must to make sure the generator will note explode if the generator can’t hold the pressure
4. Use only distilled water. Filtered water are NOT distilled water

4.6.3 Operating the generator

1. Fill the generator with DISTILLED WATER, leaving 1” of free space at the top. Add 1/8 teaspoon of Electrolyte (pure Baking Soda) to the 32oz HHO Generator.
2. Close the generator. HHO Units should draw about 2 AMPS of power. More Baking Soda may be added but, make sure the units operate cool and don't overheat. Running the units too hot will create steam and that will cause a drop in mileage and engine performance.

4.6.4 Test run on HHO generator

1. Start with no electricity, by taking out the fuse or leaving one of the terminals disconnected (make sure it doesn't touch metal parts of the engine to prevent fuse blowout).
2. Turn off the engine.
3. Connect the electricity by putting the fuse on and making sure all connections are tight (hand force only).
4. Start the engine again and watch the electrolyzing action and a yellowish gas (HHO) will start forming and flow toward the top of the generator.

4.7 Experiment Method and Variable

What will be discovered in this experiment is to see either this generator will really work on helping us to save some money on petrol. Besides that, we also need to compare the performance and also the effect to our world by using this kind of fuel efficiency device. In this experiment, what is really being the main point is the torque that will be produces before and after the system installed. Brake horse power also will be considered to see the real performance of the system. To measure all this variables, dynamometer will be use to appear the result on the screen. For the gas emissions reading, gas analyzer will be use to take the reading before and after the system installed. All the result will be compare and will be show in graph form.

For the brake horse power (BHP) and the torque reading, data will be taken from dynamometer. Several test will be perform before comparison can be make. For the performance test, 5 data will be collect from 6 difference engine speed. By using this dynamometer, engine speed will be increasing from 1000 rev/min to 1500, 2000, 2500, 3000 and 3500 rev/min for every 1 minute. After the data from normal conventional engine have been taken, the system will be installed and we will run the test again. At this time, the BHP and torque will be observed carefully to see how the performance after the system installed.

For the emissions, gas analyzer will be put at the end of the exhaust to see the differences between the system installed and not. The data will be recorded at one engine speed after and before system installed. Gas analyzer will produced the reading for Hydrocarbon (HC) in parts per million (ppm), Carbon Monoxide (CO) in percentage, Carbon Dioxide (CO_2) in percentage, Oxygen (O_2) in percentage, and Oxide of nitrogen (NO_x) in parts per million (ppm). Data at engine idle time also will be taken. All data will be compared and will be visualize in graph form. The data also will be compared to standard that have been stated by the law.

CHAPTER 5
RESULTS

5.1 Calculation of Designing Hydrogen Generator

The fabrication of the generator was completed. Here is the step in fabricating the generator and to give some picture about the generator. The generator housing contains a coil and two cylindrical electrodes; used to generate both hydrogen and oxygen. Each is made from stainless steel. The dimension for the housing is:

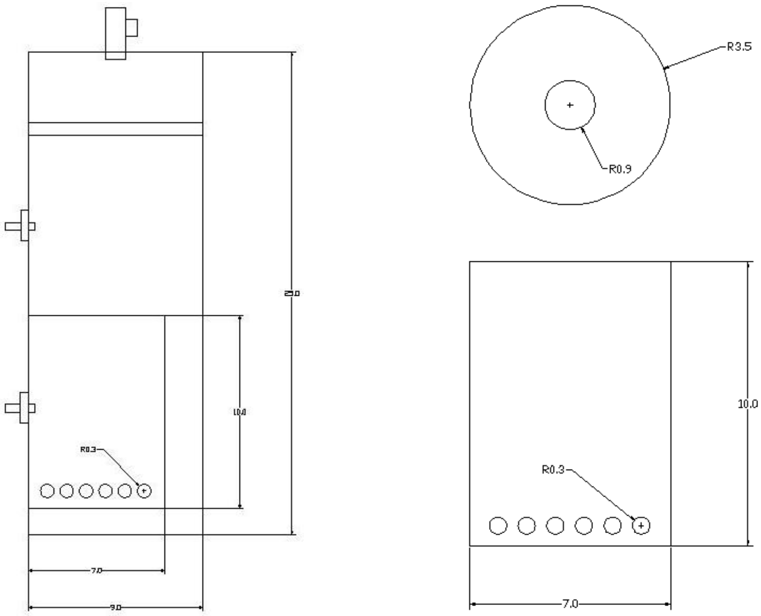


Figure 5.1: Schematic Diagram of HHO Generator [4]

All the exact dimension of the generator has been show in schematic diagram above. The total high of this generator is about 25 cm and the diameter of the generator is 9cm. This generator is in cylinder shape it can contain about 0.384 Liter of water and produce about 1 liter HHO gas when it operated. The diameter of inner electrode is 7 cm and the height is 10 cm. Below is the calculation in designing the generator. The entire dimension is accurate follow to produce good result when using this HHO generator.

Radius : 4.5 cm

Hieght: 25 cm

So, the volume of the generator is;

πr^2 x height = $(4.5)^2\ \pi$ x 25 = 1590 cm^3

= 1590/1000

= 1.59 L

The inner electrode also in form of cylindrical container with dimension:

Radius : 3.5 cm

Hieght: 10 cm

So, the volume of the generator is;

πr^2 x height = $(3.5)^2\ \pi$ x 10 = 384 cm^3

= 384/1000

= 0.384 L

However, to make this electrode to work, we need to drill 2 hole for allow the water and baking soda to pass through it. 2 x 0.5 cm radius hole need to be drill at side and bottom of the inner electrode.

Two 1 inch bolt and nut will be place at the inner electrode and outer housing as the terminal to connect the wire from generator to car battery. To prevent form any current leakage, 2 rubber washer will be place within the bolt nut for the terminal.

Plastic fitting will be place at the top of the housing for allow the hydrogen from the generator to intake manifold. 1 stop valve will be place in the middle of the tube for stop the hydrogen from generator.

0.6 cm outer diameter tube will be use to connect from generator to intake manifold. Plastic fitting will be use to connect the tube to intake manifold.

There is still several device need to be use to make sure this generator will work when its connect to power source. Below the list of the material that I need to get to run the experiment:

1) Relay
2) 30 Amp fuse
3) Water
4) Baking soda
5) Intake manifold for the engine
6) White tape
7) Wire
8) ¼ tubing shut-off valve

Below is the picture of the generator:

(a) Inner electrode

(b) Terminal

(c)Housing cap

(d) ¼ '' tube

(e) Hydrogen generator

(f) Connection

Figure 5.2: Picture of HHO Generator

5.2 Determine the Quantity of Gas Produces by the Generator

To exactly know how much hydrogen can be produce by this HHO generator, I've done some basic experiment to determine the actual quantity that the generator will produce in a minute. The set up of this experiment actually by using a 1 litre mineral bottle and it is be submersed completely in water. One end of tubing has put inside the bottle to transfer the hydrogen from outlet of the generator to the bottle. Times have been recorded to see how long the gas will completely disposed 1liter water inside the bottle. The material that was use in this experiment is:

1. The generator
2. Plastic bottle
3. ¼ tubing
4. Basins

Below is the set up how the experiments have been done.

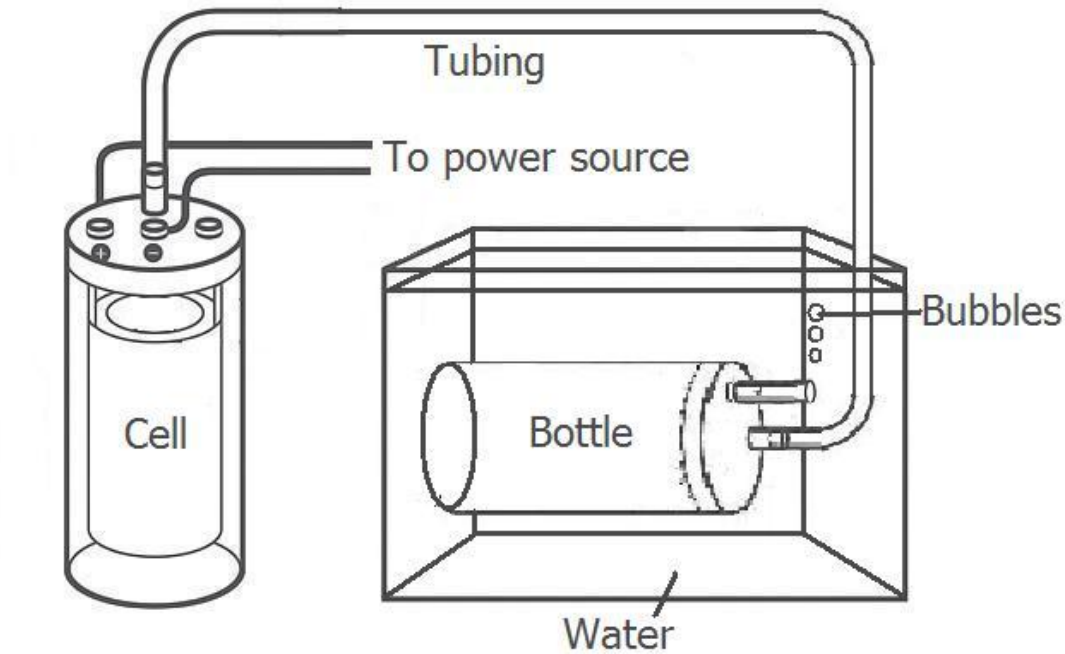


Figure 5.3: Setup for determining volume of gas produced [4]

After several experiment attempts, below is the result for the entire experiment.

Table 5.1: Result of determining volume of gas produced by generator

Test	Time for disposed 1 litre water
1	1 minute 35 seconds
2	1 minute 30 seconds
3	1 minute 27 seconds
4	1 minute 33 seconds
5	1 minute 26seconds
Total	451 seconds / 5 = 1 minute 30 seconds

So, average time for disposed 1 litre water inside the bottle is about 1 minute 30 seconds. It means the average of this generator can produce about 1 minute 30 seconds per litre.

5.3 Experiment Data for Engine Test Bed without HOD System Installed

All the result was taken using dynamometer that attach on FORD MVH 418 injection engine. No modifications have been made to the engine since we want the actual result from engine running without HOD system installed. Results have been taken for every 1 minute after we changed the engine speed manually.

We allowed to take about 6 reading only because to maintain the safety and the lifespan of the engine. Modifications of engine speed have been done manually by increasing the speed using software for the dynamometer. The engine speed that recommended by lab technicians is from 1000 rev/min until 3500 rev/min with increasing about 500 rev/min for every one minute. The results have been recorded using print screen and have been interpreted in table and graphical form.

5.3.1 Data in table form for Engine without HOD System Installed

Table: 5.2: Data in table form for Engine without HOD System Installed

Engine Speed (Rev/min)	Brake Horse power (BHP)	Torque (Nm)
1000	13.9	100
1500	16.8	80
2000	14.7	53
2500	11.6	33
3000	9.7	23
3500	6.5	13

5.3.2 Data in graph form for Brake Horse Power (BHP) VS Engine Speed (rev/min)

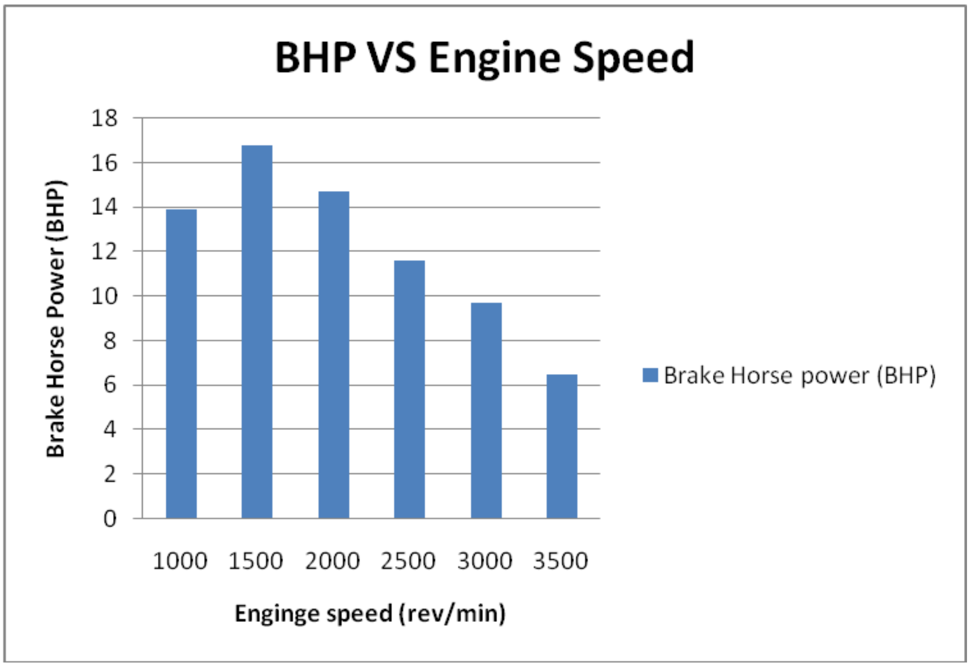


Figure 5.4: Data in graph form for Brake Horse Power (BHP) VS Engine Speed (rev/min)

5.3.3 Data in graph form for Torque (Nm) VS Engine Speed (rev/min)

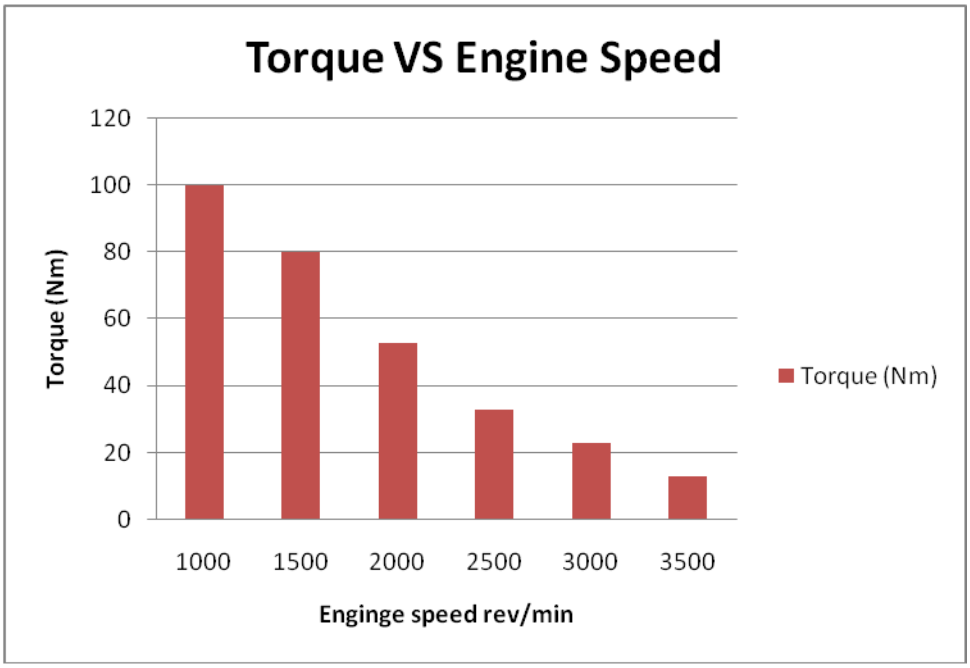


Figure 5.5: Data in graph form for Torque (Nm) VS Engine Speed (rev/min)

5.4 Experiment Data for Engine Test Bed with HOD System Installed

All the result was taken using dynamometer that attach on FORD MVH 418 injection engine. Modifications have been made to the engine by adding HHO generator since we want the result from engine running with HOD system installed. Results have been taken for every 1 minute after we changed the engine speed manually. The HHO generator can produce about 1 liter hydrogen and oxygen gas in about 1 minute and 30 seconds. So for every minute, the generator will produce about 0.67 liter per minute and transfer it to the engine by vacuum in intake manifold hose. The connections must be made near the intake manifold to make sure the effect of vacuum applied inside the hose.

We allowed to take about 6 reading only because to maintain the safety and the lifespan of the engine. Modifications of engine speed have been done manually by increasing the speed using software for the dynamometer. The engine speed that recommended by lab technicians is from 1000 rev/min until 3500 rev/min with increasing about 500 rev/min for every one minute. The results have been recorded using print screen and have been interpreted in table and graphical form.

5.4.1 Data in table form for Engine with HOD System Installed

Table 5.3: Data in table form for Engine with HOD System Installed

Engine Speed (Rev/min)	Brake Horse power (BHP)	Torque (Nm)
1000	14.0	103
1500	17.0	81
2000	14.9	53
2500	11.8	35
3000	9.8	24
3500	6.6	15

5.4.2 Data in graph form for Brake Horse Power (BHP) VS Engine Speed (rev/min)

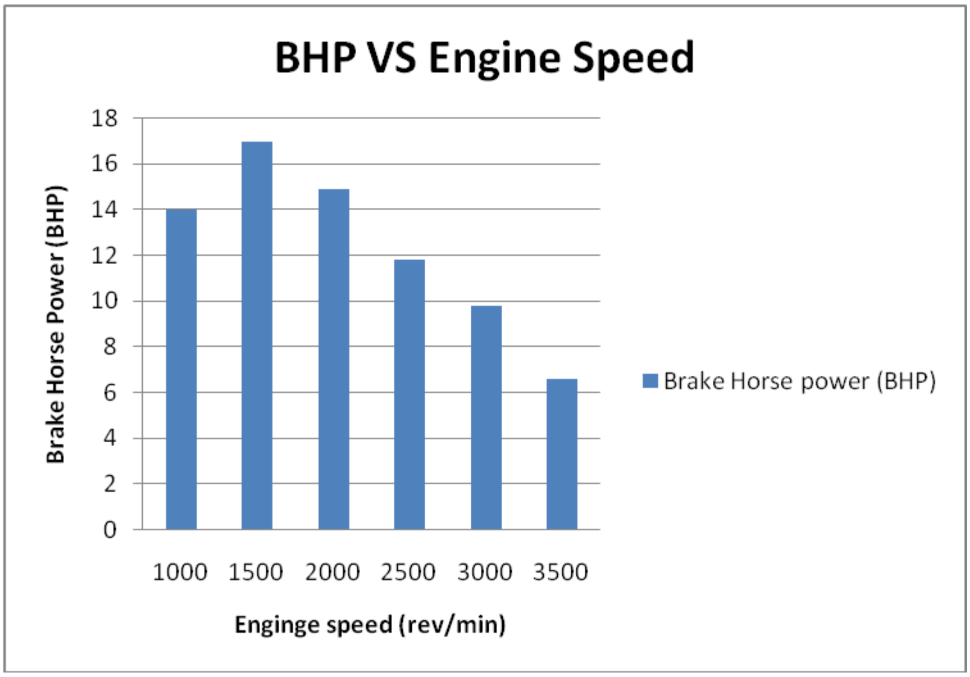


Figure 5.6: Data in graph form for Brake Horse Power (BHP) VS Engine Speed (rev/min)

5.4.3 Data in graph form for Torque (Nm) VS Engine Speed (rev/min)

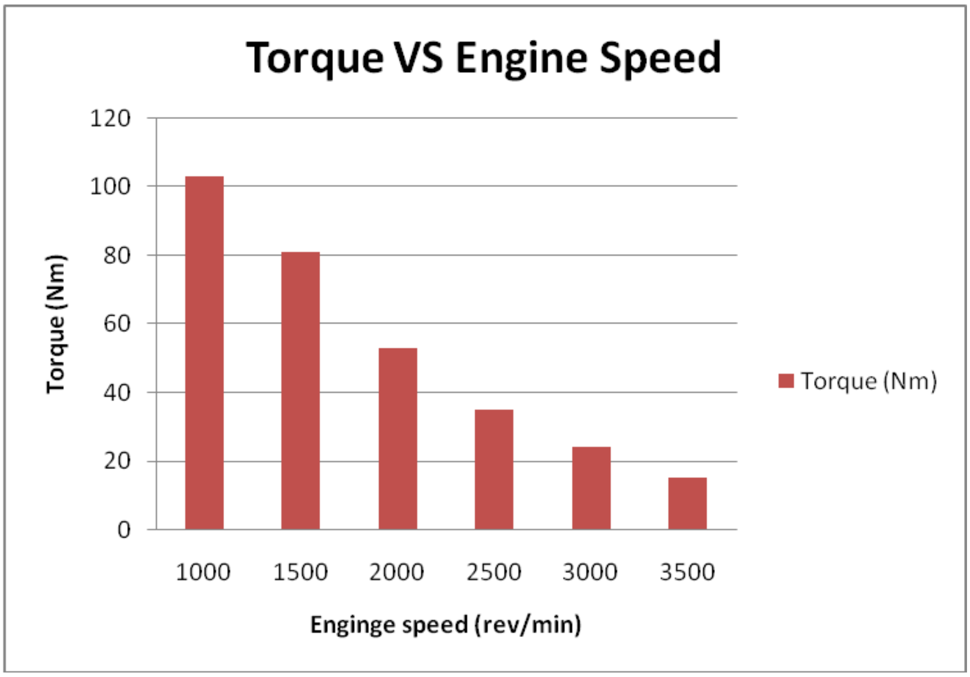


Figure 5.7: Data in graph form for Torque (Nm) VS Engine Speed (rev/min)

5.5 Comparison Result for Brake Horse Power (BHP) Between Before and After HOD System Installed

Table 5.4: Comparison Result for Brake Horse Power (BHP) Between Before and After HOD System Installed

Engine Speed (Rev/min)	Brake Horse Power		Percentage different (%)
	Before (BHP)	After (BHP)	
1000	13.9	14.0	0.7
1500	16.8	17.0	1.1
2000	14.7	14.9	1.36
2500	11.6	11.8	1.72
3000	9.7	9.8	1.03
3500	6.5	6.6	1.53

5.5.1 Comparison of brake horse power (BHP) value between with and without HOD system according to engine speed (rev/min)

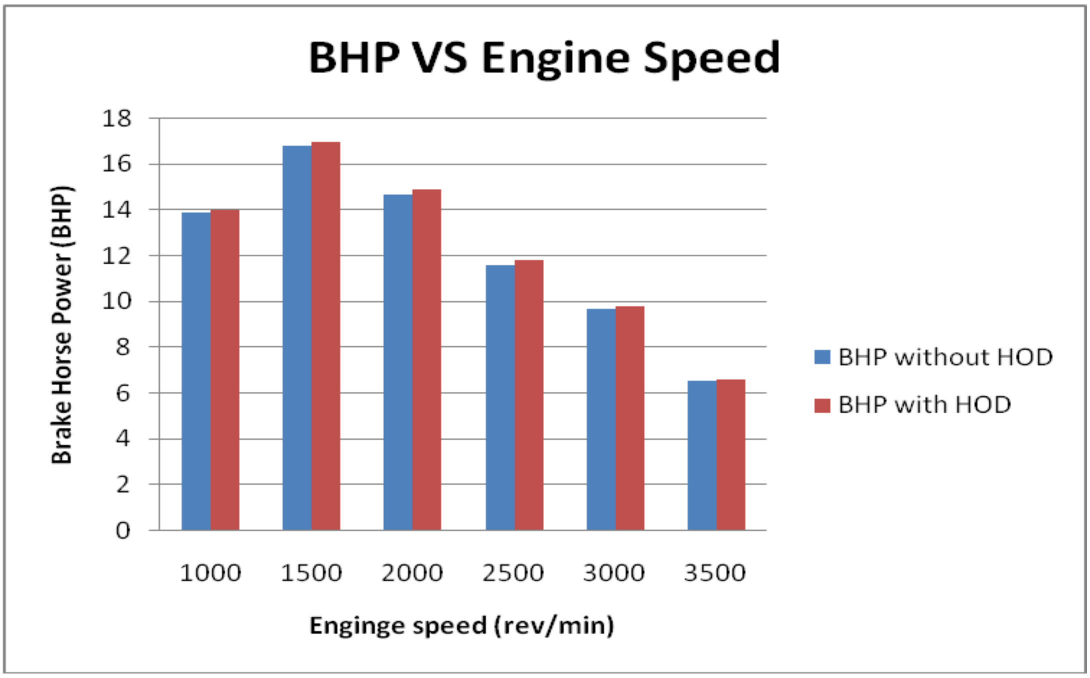


Figure 5.8: Comparison of brake horse power (BHP) value between with and without HOD system according to engine speed (rev/min)

5.6 Comparison Result for Torque (Nm) Between Before and After HOD System Installed

Table 5.5: Comparison Result for Torque (Nm) Between Before and After HOD System Installed

Engine Speed (Rev/min)	Torque		Percentage different (%)
	Before (Nm)	After (Nm)	
1000	100	103	3
1500	80	81	1.25
2000	53	53	0
2500	33	35	6.06
3000	23	24	4.34
3500	13	15	15.3

5.6.1 Comparison of torque (Nm) value between with and without HOD system according to engine speed (rev/min)

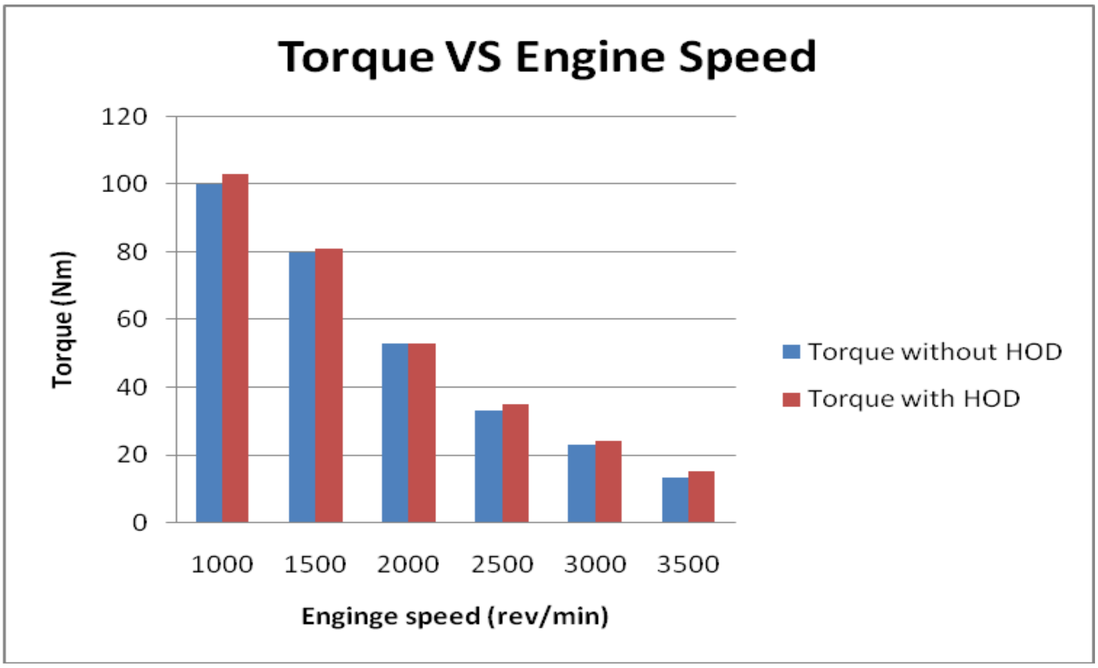


Figure 5.9: Comparison of torque (Nm) value between with and without HOD system according to engine speed (rev/min)

5.7 Percentage difference of BHP and torque value between with and without HOD system installed according to engine speed

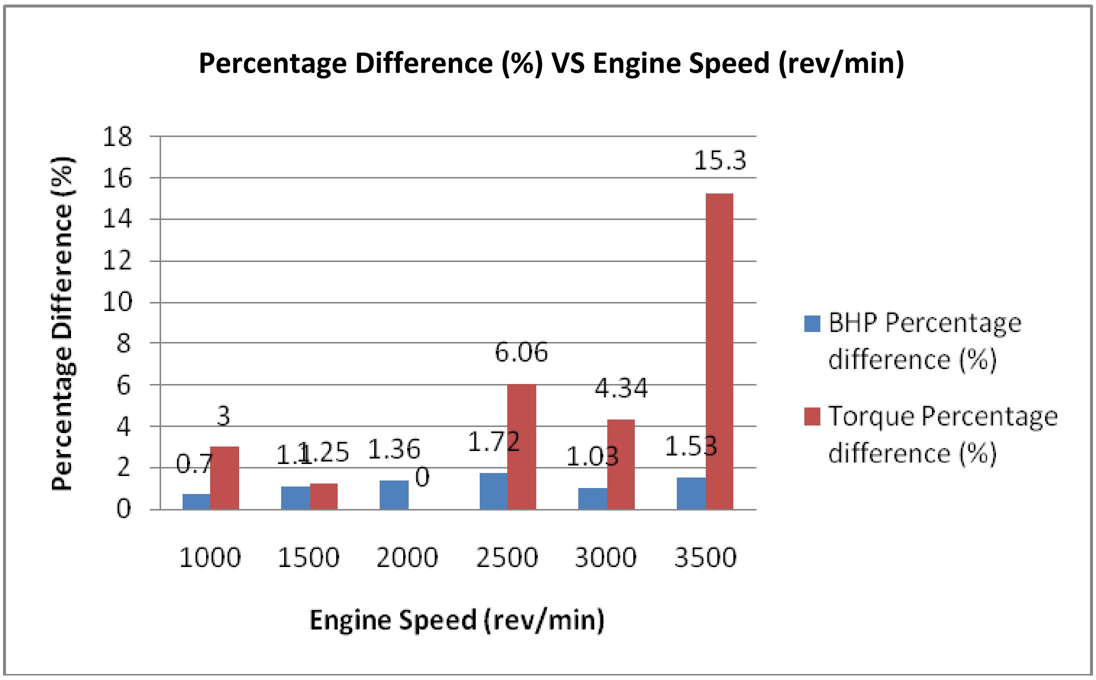


Figure 5.10: Percentage difference of BHP and torque value between with and without HOD system installed according to engine speed

From the all results and data that have been gathered, what can be conclude, this HOD system does not really effective on this type of engine. From what have been observed, the highest percentage different after using this system is about 1.72% for brake horse power (BHP). 1 horsepower equivalent to 745.7 watts. This indicates, the performance will not really increase after installing this system on injection engine. For torque produces, the result have slightly changes. The higher percentage for torque is about 15.3%, still not to call it increasing in performance.

After doing more deeply research on this topic, finally I have found some recommendations and modifications that can be apply to make sure this system can work more efficiently. Several steps also can be considered to improve the safety in using this HHO generator. What can be recommended here is to try to implement this system on carburettor engine beside the injection. From what I have read, this HHO generator will work more efficiently on carburettor engine. It is because the carburettor engine doesn't have some sort of computer or ECU to control the variables likes air/fuel ratio and others that have a big influence in improving car's performance meanwhile safe some hard earned cash.

To completely experiencing this effect of HHO system on injection engine, more deeply study or experiment can be done with the recommended modifications below.

1. Change the composition of baking soda plus distilled water with citric acid plus distilled water.
2. Use Electronic Fuel Injection Enhancer (EFIE). The EFIE allows to apply an offset to the voltage coming from t he oxygen sensor, so the engine computer is completely unaware that t he oxygen content of the exhaust has increased .
3. Use more than one generator. In this case, hopefully by using more than one generator it can produces more Hydrogen gas.
4. Improve the design of HHO generator. With improvement of generator such as material for electrode, electrode size and the size of the container itself will have more effect in producing more Hydrogen.

All recommendations above can be done to improve the using of HHO generator. Besides the improvement on generator itself, the way of driving also will give a good impact in safe money to buy gasoline. This HHO generator have a big potential in contributing to the world in keeping the environment unpolluted besides save a bit of money while have a more efficient car performance.

5.8 Results on Gas Analyzer Test

For this experiment, we use gas analyzer that prepared by UTP. In this test, only Hydrocarbon (HC), Carbon Monoxide (CO_2), Carbon dioxide (CO) and Oxygen (O_2) have been recorded due to limitations of equipment. To record the data, we took the reading during the test at engine speed 2500 rev/min. The test has been done to both after and before HOD system been installed. Below is the result for the emissions test.

Table 5.6: Emissions test at 2500 rev/min

	HOD System Installed	
	Before	After
Hydrocarbon (HC) ppm	10	2
Carbon Monoxide (CO) %	0.1	0.02
Carbon Dioxide (CO2) %	15.2	14.9
Oxygen (O2) %	19.5	18.1

From this table, its show some improvement on emissions of exhaust gas after using the HOD System. However, there still have room for improvement to get more clean emissions beside use this HOD System. There is several step can be consider to be applied. As example, excessive of CO, may result from rich air/fuel mixture. What can we do is to make sure all the setting such as O_2 content or throttle position is correct. To avoid excessive in HC, we need to make sure no leaking at intake manifold or no worn at throttle shaft. Incorrect spark timing also may cause excessive in HC.

CONCLUSION

What can be conclude here, HHO generator does produces HHO gas that is hydrogen and oxygen gas and can be use in order to have more efficiently combustion of gasoline. From what have been observed, HHO gas has contribute a little bit to the cars performance by have slightly increasing in torque and power output. Furthermore, it's also shown a good characteristic of producing more clean emissions to our environment. To have more effects of using this generator, several steps have been recommended to be applying when installing this system in our car. From what have been written by others, this HHO generator is really suit on carburetor engine. It is because, injection have ECU that control the amount of oxygen that the car will be use inside the combustion chamber. To have this successful to injection engine, we have to do some modifications of electric circuit by adding a device called electronic fuel injection enhancer to allowed the tamper in oxygen usage of our engine. Besides that, to have more efficient way to use this HHO generator, we can installed onboard indicator that can show us about the temperature of the engine, water level inside the generator an also the flow rate of the hydrogen transfer to the engine. With this onboard indicator, we can closely monitor the conditions of the generator while using it to the maximum. These projects have very good potential to widely discover and to be commercialized. We can really save our money besides having a good performance car and give the cleaner emissions to our world by using this generator.

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APPENDIXES

Data in Print Screen from Dynamometer Computer for Engine without HOD System Installed

1000 rev/min (without HOD System installed)

Figure 5.3: 1000 rev/min (without HOD System installed)

1500 rev/min (without HOD System installed)

Figure 5.5: 1500 rev/min (without HOD System installed)

2000 rev/min (without HOD System installed)

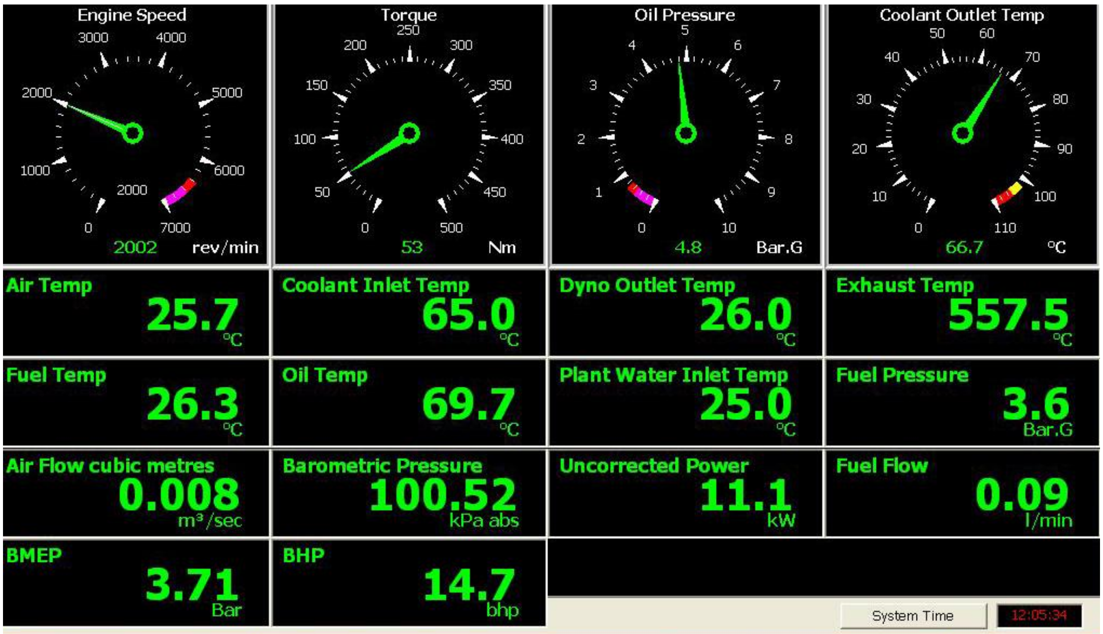

Figure 5.5: 2000 rev/min (without HOD System installed)

2500 rev/min (without HOD System installed)

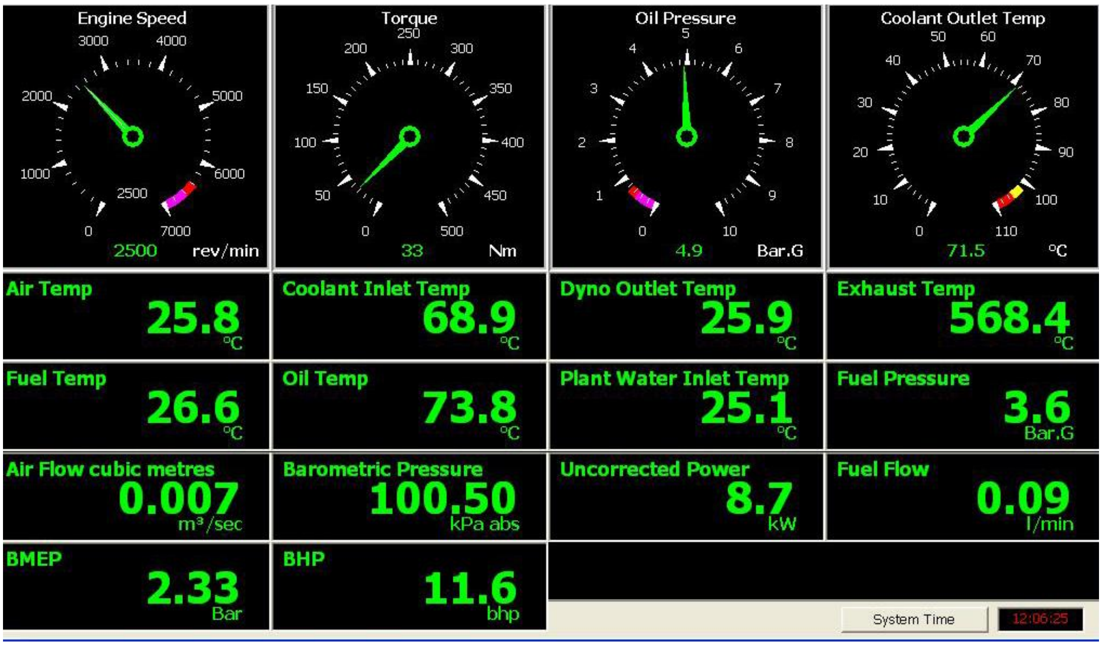

Figure 5.6: 2500 rev/min (without HOD System installed)

3000 rev/min (without HOD System installed)

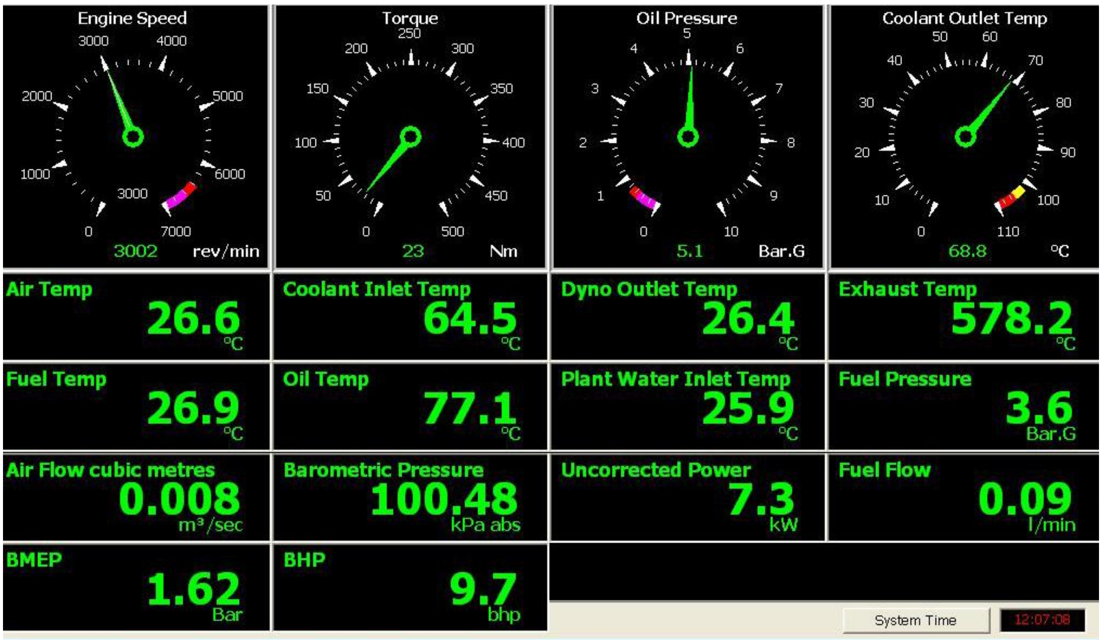

Figure 5.7: 3000 rev/min (without HOD System installed)

3500 rev/min (without HOD System installed)

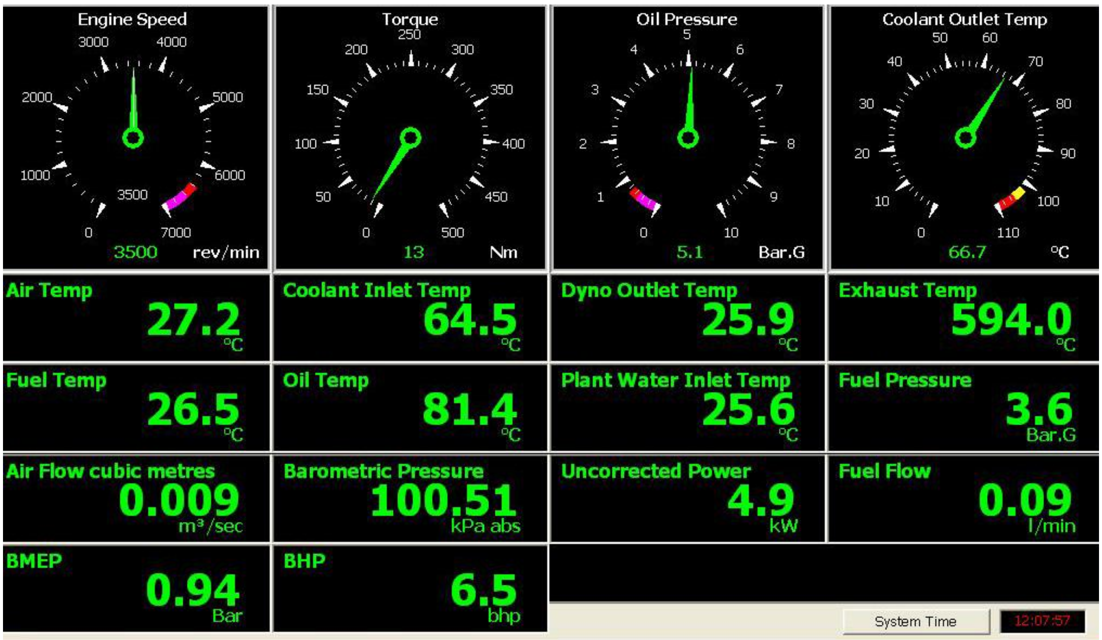

Figure 5.8: 3500 rev/min (without HOD System installed)

Data in Print Screen from Dynamometer Computer for Engine with HOD System Installed

1000 rev/min (with HOD System installed)

Figure 5.11: 1000 rev/min (with HOD System installed)

1500 rev/min (with HOD System installed)

Figure 5.12: 1500 rev/min (with HOD System installed)

2000 rev/min (with HOD System installed)

Figure 5.13: 2000 rev/min (with HOD System installed)

2500 rev/min (with HOD System installed)

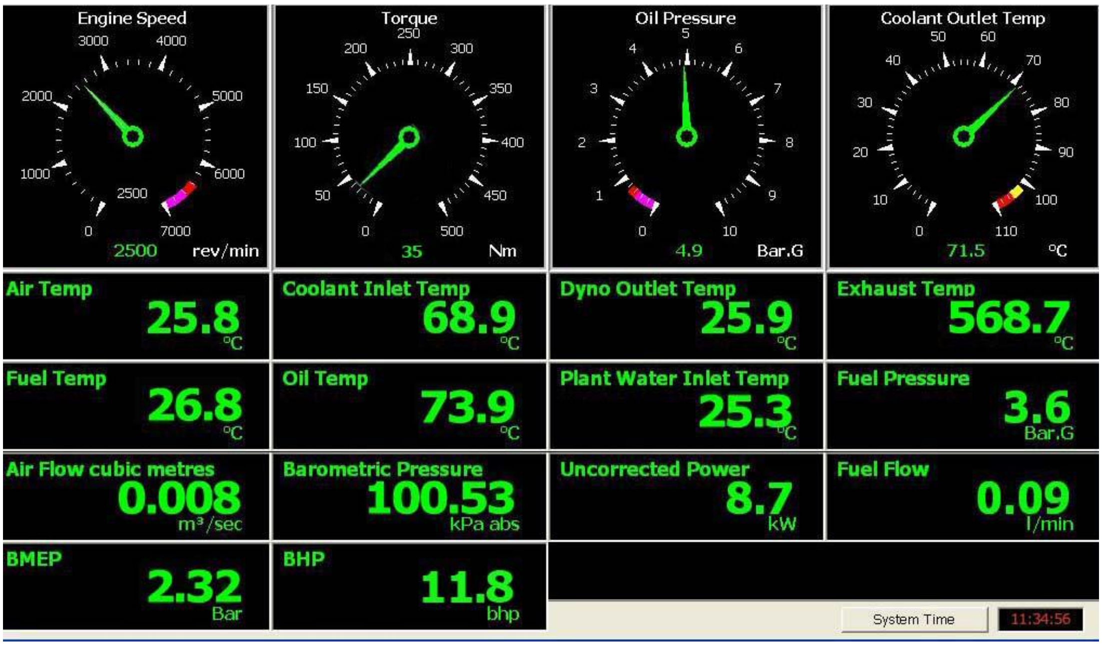

Figure 5.14: 2500 rev/min (with HOD System installed)

3000 rev/min (with HOD System installed)

Figure 5.15: 3000 rev/min (with HOD System installed)

3500 rev/min (with HOD System installed)

Figure 5.16: 3500 rev/min (with HOD System installed)