NOR HAZWANI BINTI ABDUL JALIL

B. ENG. (HONS) MECHANICAL ENGINEERING

JANUARY 2010

ENGINE AND FUEL CONSUMPTION OPTIMIZATION FOR COMPETITION IN SHELL ECO MARATHON 2010

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by

Nor Hazwani bt Abdul Jalil

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

JANUARY 2010

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

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BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

Approved by,

____

(Ir. Dr. Masri bin Baharom)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2010

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.

NOR HAZWANI BINTI ABDUL JALIL

ABSTRACT

This Final Year Project (FYP) Report is briefly discusses on research and study of engine and fuel consumption optimization for competition in Shell Eco Marathon 2010. The engine and fuel consumption testing will held throughout the research to ensure the theoretical study applied practically during the competition. The main objective of this project is to fabricate and modified engine that ensure vehicle travel farthest with less amount of fuel and to optimize the engine performance so that it consume less amount of fuel during operation.

The main focus of the project is converting the carburetor to electronic fuel injection system. This will greatly improve engine reliability, consistency, and ultimately fuel consumption. These improvements are needed because there are many problems inherent in traditional carburetion. These include imprecise fuel metering, poor ability to adapt to changing load and environmental conditions, and long-term inconsistency [1]. To encounter of relatively crude tuning controls, the Alpha – N EFI system using a throttle position sensor and an optical encoder for engine position and speed is used [1]. The injector pulse time will be precisely controlled by 16 bit micro controller based on data taken from the sensors in real time. This controller will collect data from sensors during engine testing on dynamometer, in which the load on the engine is gradually increased [2]. Engine also undergo trial run to calculate the km/L of the vehicle from original engine which is carburetor until it convert to EFI system. Besides that, modification on exhaust length is done to enhance the air flow and volumetric efficiency of the engine. The fuel consumption of vehicle is improved about 50% of its original result from 500 km/L to 1125 km/L.

ACKNOWLEDGEMENT

Throughout the progress of my Final Year Project, I would like to acknowledge my family for always being there to provide moral support to me as well as to help me to obtain the data or information needed when there was a time constraint on me for being unavailable to return to my Internship host company to take the required data. My family also provided their knowledge on the respected field in order for me to input to the FYP as additional information.

The next acknowledgement would be tribute towards my Final Year Project supervisor which is Ir. Dr. Masri bin Baharom. During the progress of the FYP, Ir. Dr. Masri provided lots of feedback that is related to the project as well as provided his valuable experience on the subject. He also introduced to me the aspects needed to do my FYP and the methods which are to be used to analyze the project so that the needed result can be obtained. Besides that, Ir. Dr. Masri always encouraged us to do the best and that the project can be solved by multiple methods and that it is important that we do not stray from the main topic and that it is better to provide more alternatives for the project so that with more choices, chances that a better alternative can be found.

The next acknowledgement would be diverted to the various staff in my Internship host company which is Powertrain, PETRONAS Research Sdn. Bhd. but most of the credit would be given to my supervisor at the host company which is Mr. Syed Omar bin Syeikh Alsagoff who provided I mostly with the knowledge needed to cope with the testing conditions as well as how to manage and deal with engine testing. Besides that, I want to thank the technician in Building 15, 17, 20 and 21 who helps me in fabricating the new engine part for my FYP. Their help and opinion help a lot. They also help me handling the equipment and provide the material for fabrication. My FYP would not be finish in time without help from all of them. I sincerely thank all of the people who contribute in my FYP and it is an honor to work with all of them.

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CHAPTER 1: INTRODUCTION

1.1 Project Background

The Shell Eco-marathon Asia 2010 competition challenges students around the world to design, build, and test vehicles that travel further using less energy [3]. It is an educational platform that encourages innovation, reinforces conservation and fosters the development of leading technology for greater energy efficiency where global forum for current and future leaders who are passionate about finding sustainable solutions to the world's energy challenge [5]. In conjunction with Shell Eco Marathon, team is required to build a simple vehicle that will be raced in term of having the lowest fuel consumption per distance traveled. A single cylinder four stroke engine is used and required improvement to further reduce its fuel consumption by studying the parameter affecting the fuel usage and conducting experiment and testing to achieve the desired results. The current single cylinder four stroke engine is using carburetors that lead to high fuel consumption. Carburetors were the predominant method used to meter fuel on gasoline engines before the widespread use of fuel injection [2]Thus, a fuel injection system for gasoline called alpha – N system is designed and calibrated as required for this competition to enhance the fuel consumption. The alpha – N system uses throttle position and optical encoder (engine speed) sensor only. The primary difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on low pressure created by intake air rushing through it to add the fuel to the airstream [4]. Besides that, exhaust length will be modified to get a better air flow to the engine that helps to improve the fuel consumption. The entire engine testing before and after modification will be done on dynamometer. Dynamometer is a tool used for engine testing and the data obtained from this will be used as bench mark for better fuel consumption improvement for the engine.

1.2 Problem Statement

The current vehicle engine is using carburetor that leads to high fuel consumption. Thus, modification on carburetor single cylinder four stroke engines to fuel injection system is done to ensure the engine will has low fuel consumption. Besides that, exhaust length will be modified to enhance the air flow that lead to fuel consumption improvement.

1.3 Objective

- To fabricate and modified engine that ensure vehicle travel farthest with less amount of fuel
- To optimize the engine performance so that it consume less amount of fuel during operation.

1.4 Scope of Study

The scope of study for this project can be divided into three sections as below:

- **Engine testing to determine the standard performance of current engine**

    - To gather information about the engine characteristics such as torque, power and fuel consumption.

- **Modification to engine parameter**

  - Modification of carburetor engine to fuel injection system called Alpha – N system.
  - Modification on exhaust length.

- **Overall Engine Testing**

  - To determine the performance of engine after modification and comparing the result with the original engine performance.
  - Further fine tuning.

CHAPTER 2: LITERATURE REVIEW

2.1 Engine HONDA GX 35

The team has chosen 3.5 cc and 1.6 HP HONDA GX 35 engine for the UTP-SEM 2010 (Universiti Teknologi PETRONAS – Shell Eco Marathon 2010) vehicle. It is a small single cylinder four stroke engine, over head cam (OHC) and carbureted motor which is a lawn mower. It is one of the most used engines for Shell Eco Marathon cars, as it is small, light and low fuel consumption. The only downfall in this engine is currently used carburetors which were not able to adjust the amount of fuel that get fed into the engine [11]. The carburetor feeds a predetermined amount of fuel into engine depending on the air flow in the intake, so to enhance the fuel consumption and efficiency of the engine its need to be modified to Electronic Fuel Injection (EFI) [7]. The improvement of carburetor to Electronic Fuel Injection (EFI) has been decided through research from other teams who enter Shell Eco Marathon previously such as Isfahan University of Technology, Fancy Carol, University of Massachusetts Amherst and many more. It is proven that EFI enhance fuel consumption and efficiency of the engine. The engine total weight of 3.3 kg has reduced to 2.6 kg after removed unnecessary accessories on the engine and it helps to improve fuel consumption when the vehicle is light.

Figure 1: HONDA GX 35 engine [6]

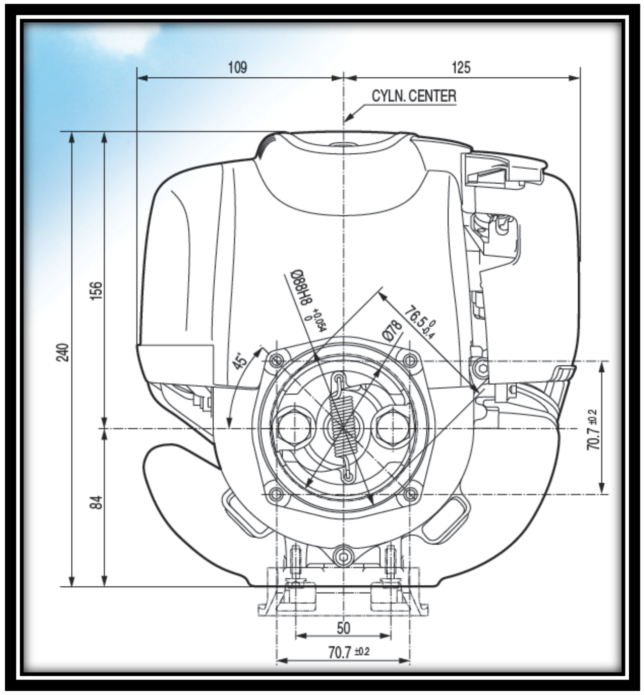


Figure 2: Left side view of HONDA GX 35 [6]

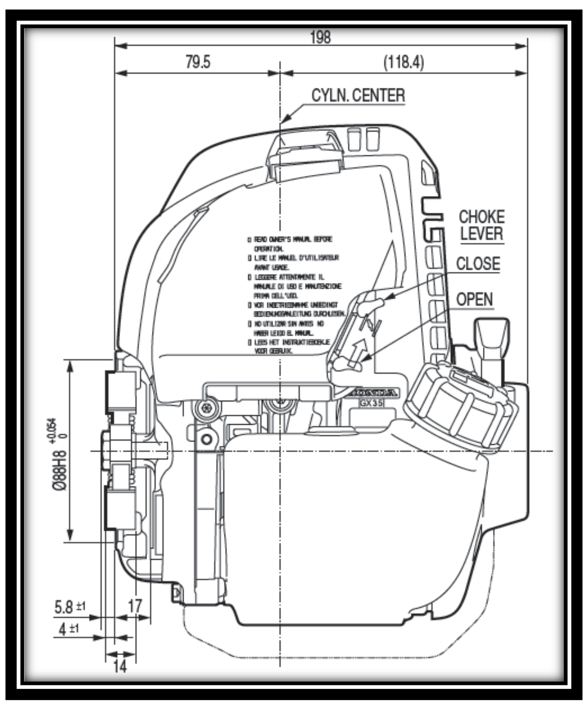


Figure 3: Right side view of HONDA GX 35 [6]

Below shows the Output and Torque graph with its characteristics for Honda GX 35:

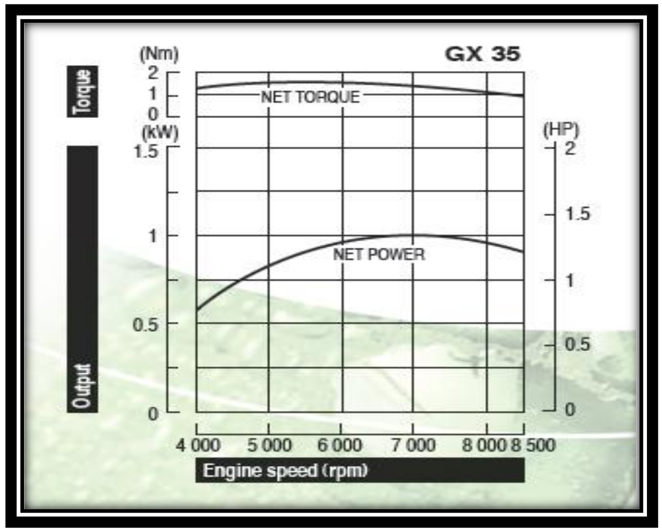


Figure 4: Engine speed vs. Output power and Torque [6]

MODEL GX 35	
Engine Type	Air cooled 4 – stroke single cylinder OHC petrol engine
Bore x Stroke	39 mm x 30 mm
Displacement	35.8 cm^3
Compression ratio	8 : 1
Net Power	1.0 kW(1.3 HP)/7000 rpm
Max net torque	1.6 Nm/0.16 kgfm/ 5500 rpm
Ignition system	Transistorised
Starting system	Recoil
Fuel Tank capacity	0.63 L
Fuel cons. at rated power	0.71 L/hr – 7000 rpm
Lubrication	Crankcase pressure driven
Engine Oil capacity	0.1 L
Dimension (L x W x H)	196 mm x 234 mm x240 mm
Dry weight	3.33 kg w/o clutch

Table 1: Engine Specification of Honda GX 35 [14]

2.2 Engine mounting and coupler for engine testing

The dynamometer was used during the engine testing phase of the project for engine tuning and efficiency. Since the dynamometer available is for other engine testing, the new coupler and engine mounting need to be fabricate to ensure the engine can be installed in dynamometer. Variation in engine turning moment is coupling the engine to the dynamometer [4]. This variation gives rise to equal and opposite reactions on the engine, which tend to cause rotation of the whole engine about the crankshaft axis [16]. Besides that, the main problem in engine mounting is that to ensuring that the motions of the engine and the forces transmitted to the surroundings as a result of the unavoidable forces and to keep it at manageable level. Below is the picture of coupler and engine mounting installed in dynamometer by others university:

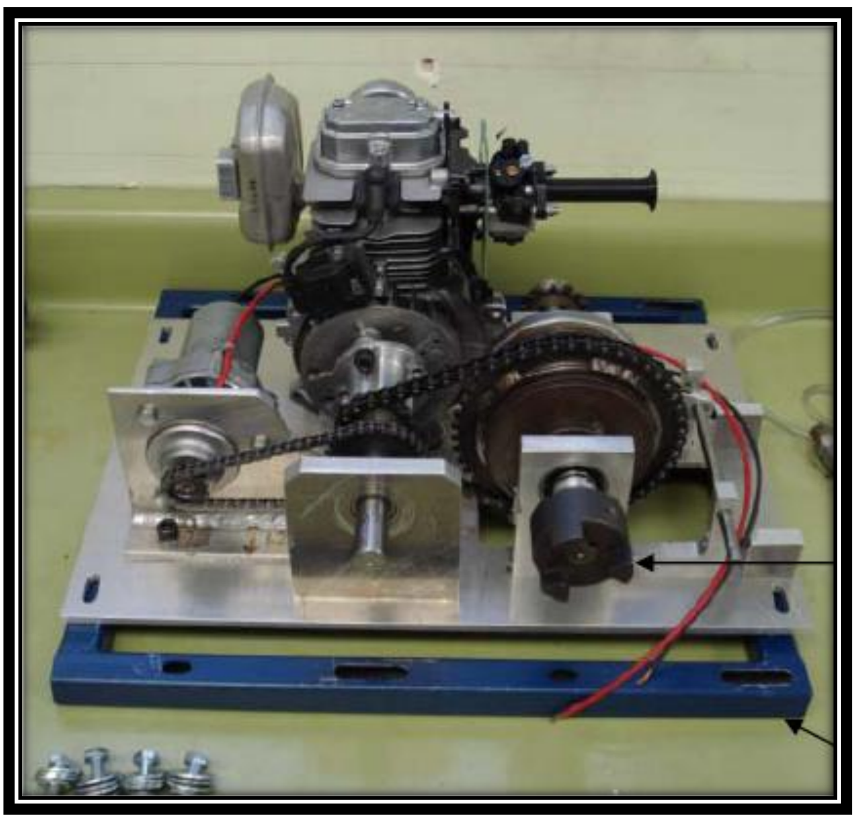


Figure 5: Engine mounting and coupler to dynamometer [10]

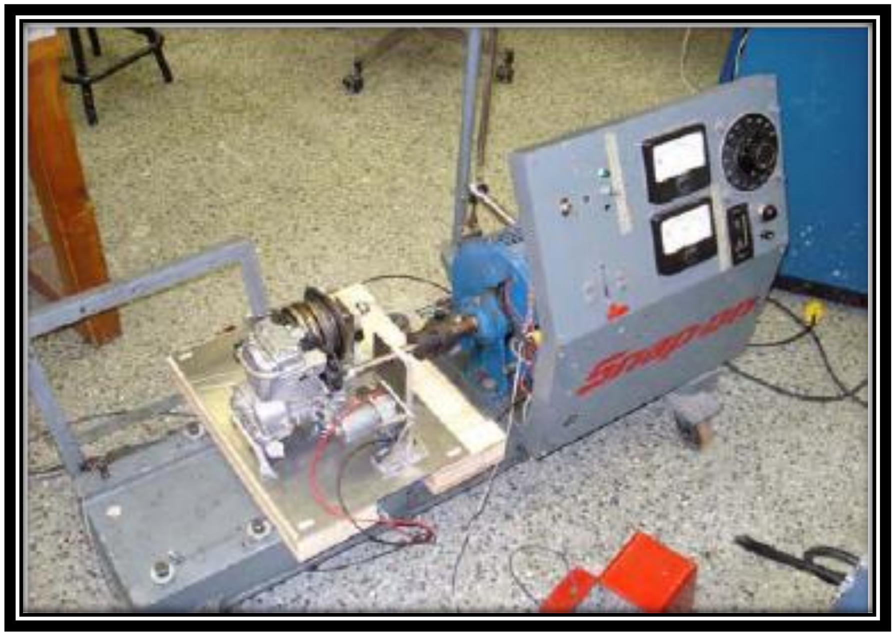


Figure 6: Dynamometer and engine assembly [10]

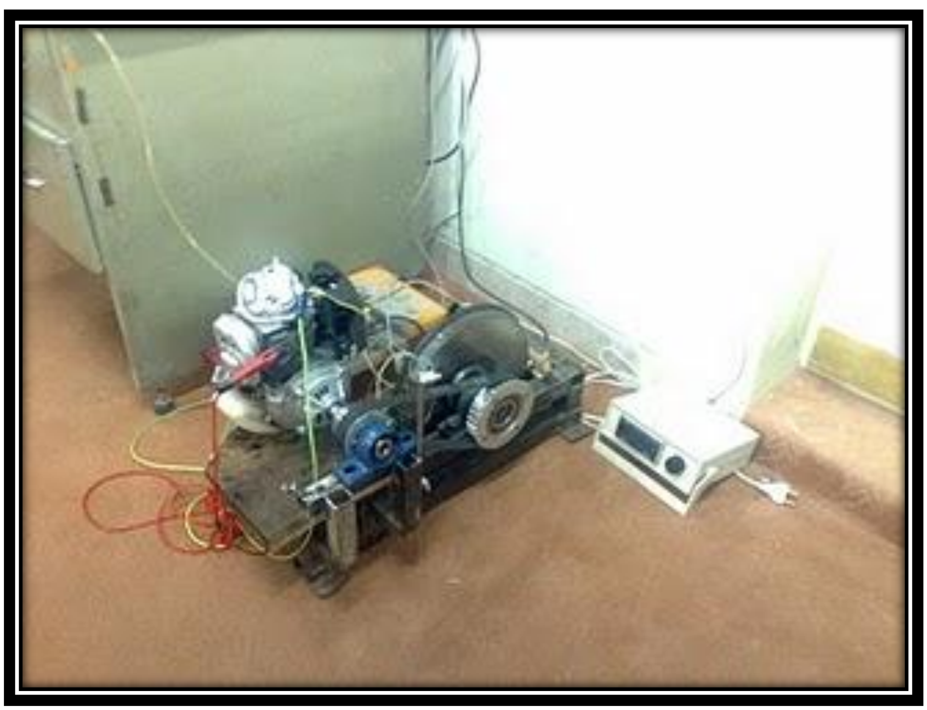


Figure 7: Engine mounting and coupler by UIT Supermilage Team [22]

2.3 Exhaust length

Parallel with the implementation of alpha-N system, the exhaust length will be modified in order to reduce pulsed effects that create obstruction for gas flow. Gases flow through intakes, exhaust and manifolds in a pulsed manner [10]. Pulse waves travel down the length of the manifold until they reach the end. At the end of the manifold, or at an obstruction, the waves create a reflected pressure wave back into the manifold. These waves can either reinforce or cancel each other. In the case of an intake manifold, one looks for the waves to reinforce at the intake valve and create a higher-pressure area to force more air into the combustion chamber [11]. This gives the engine a greater volumetric efficiency. The opposite is true for the exhaust side of the engine, were the waves should cancel one another to produce a lower pressure area at the exhaust value to help draw more exhaust gas out of the cylinder. This gives the engine a greater volumetric efficiency [18]. This modification has been made by Dalhousie University and the picture of modification as below:

Figure 8: Modified exhaust by Dalhousie University [11]

2.4 Electronic Fuel Injection (EFI) – alpha N system

The current Honda GX 35 used carburetor which is an ineffective in terms of fuel consumption. Thus, the engine will be modified to EFI called alpha-N system which gets the name from Alpha for the angle of the throttle plates and N for RPM [8]. The basic theory behind the injection system was as follows, the alpha-N system uses the throttle position and engine speed to estimate an engine load. Based on this theoretical load, it sets a particular injector (open) time. This system works by "train" the computer what to do in a given situation during dynamometer testing [7]. For every possible combination of throttle position and rpm, the tuner determines the appropriate ignition timing and fuel delivery to yield max power but not incur explosion or denotation. The computer just remembers all this in the form of maps which are stored on a chip. When it sees a certain combination of rpm and throttle position in the field, the engine act as programmed in dynamometer. So it explains how throttle position and RPM are the two dominant input parameters to the engine computer.

The alpha-N system is chosen since it used by the Fancy Carol team which holds the world Super Mileage Record of 4079.1km/L [9]. Below is the picture alpha – N system with controller.

Figure 9: alpha -N system with controller [9]

Below is the specification of alpha – N system:

Throttle body	
Type	Rotary valve with the fuel injector holder, bore 16 mm
Material	Aluminum
Weight	450 g
Applicable engine	Small engine
Appended goods	One injector and one air filter

Table 2: Throttle body specification

Controller	
Control	16 bit micro – controller
Injection time width	▪ Wide open throttle (WOT) and idle(ID) ▪ Two points only ▪ Setting by dial ▪ Displaying on LCD ▪ Range = WOT/5 to 25 m/s Idle/1 to 6 m/s ▪ Start up compensation (injection) = injected once at starting control
Injection timing	The injection start at CAM CYCLE or CRACNK CYCLE pulse sensor input (1 pulse to 1 injection)
Fuel pump control	▪ Controlled by the cycle and driving time width ▪ The cycle can be switched on WOT/ID ▪ Adjustment range 0 -500 ms and continuously drive at driving time
Revolution speed limiter	Input set value with the dial. The injection is cut when the rotational speed of the engine exceeds a set RPM

Display	(1) Amount of fuel [cc] (2) Running Distance (Trip) & Total running distance (ODO). [*1] (3) Fuel consumption. (= Running Distance/Amount of fuel [km/L]) (4) Vehicle speed. [km/h] (5) Engine speed. [r.p.m.] (6) Engine hour meter.[h.m.s] (7) Supplied voltage. [Volts] (8) Temperature. [degree Celsius] [*2]
Size / Weight	W x H x D : 107mm x 40mm x 41mm About 200g
Appended goods	▪ Wiring harness ▪ Cam sensor ▪ Wheel sensor ▪ Temperature sensor

Table 3: Controller specification

Figure 10: alpha - N system controller [9]

The controller for alpha – N system is very simple and easy setting by the digital dial. Injection control is just only for idling and wide open throttle. The fuel injection control is equipped with the “Meter Function”. It makes the injection control even better and easy to use during the race. This controller controls the fuel injection time to two engine conditions of “Wide open throttle” (WOT) and “idle position” (ID)[9]. This is not “Map control” but “two point control”. When “idle position switch” turns to “ON” (throttle close), the controller switch “injection time” from “WOT injection time” to “ID injection time”. This simple control method is designed on the assumption that the engine is driven with the wide open throttle completely [9]. It is a method of driving the engine to maximize fuel efficiency. This control method has the following advantages:

- The setting is easy with only two point
- It is easy to understand the condition of engine
- It is easy to find the engine trouble

Besides that, the controller can cut the fuel when the rotational speed of the engine is faster than the rotational speed that has been set to “Rev. limiter” setting. To improve the engine starting, the controller can inject the fuel beforehand [9]. The fuel is injected once without engine rotation, when you turn on the "fuel injection function switch". The driver must decide the times of "turn on and off" (the times of injection=amount of fuel), according to the condition of the engine at that time. The Controller injects fuel once when "injection function switch" is turned on before starting the engine. "One time" is enough usually. For this function, you can set this "start up injection time" to "WOT injection time" or "ID injection time”.

Besides that, there is one more team which implements this technology to their engine. The team is Cal Super Mileage from University of Massachusetts Amherst. This team modified the alpha-N system in their own way. They machined the alpha-N system using milling machine and alter it to suit their engine. The throttle body used a ball valve style throttle valve instead of the traditional butterfly valve to make a higher flow system [7]. The injector was a custom made 30cc/min build by Fancy Carol in Japan. Below is the picture of alpha-N system by Cal Super Mileage:

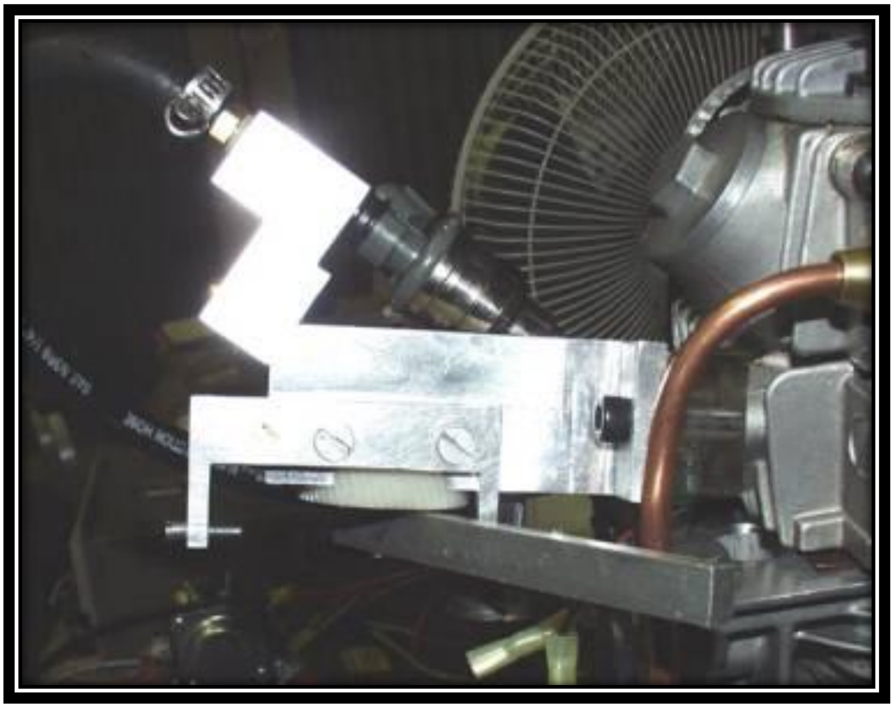


Figure 11: Throttle body with injector [7]

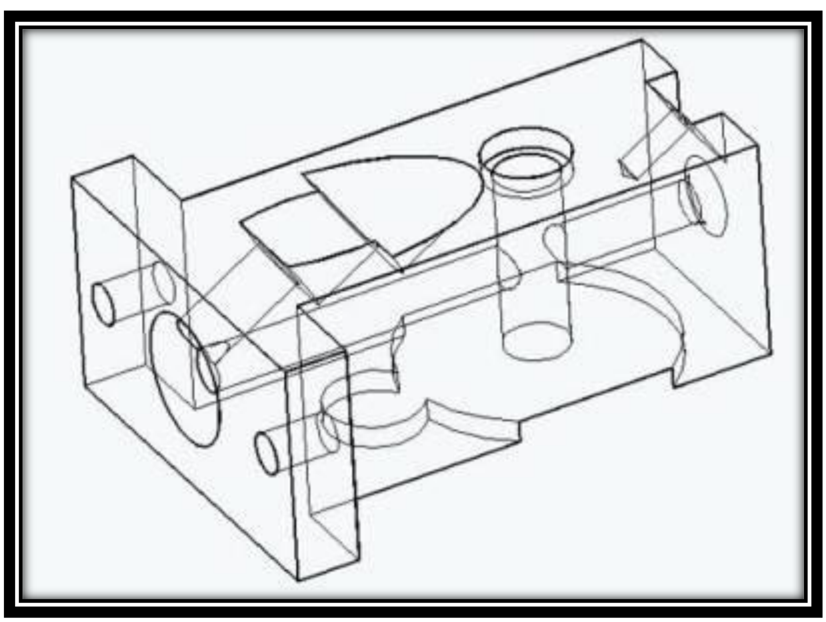


Figure 12: Wireframe drawing of alpha-N system [7]

2.5 Fuel System

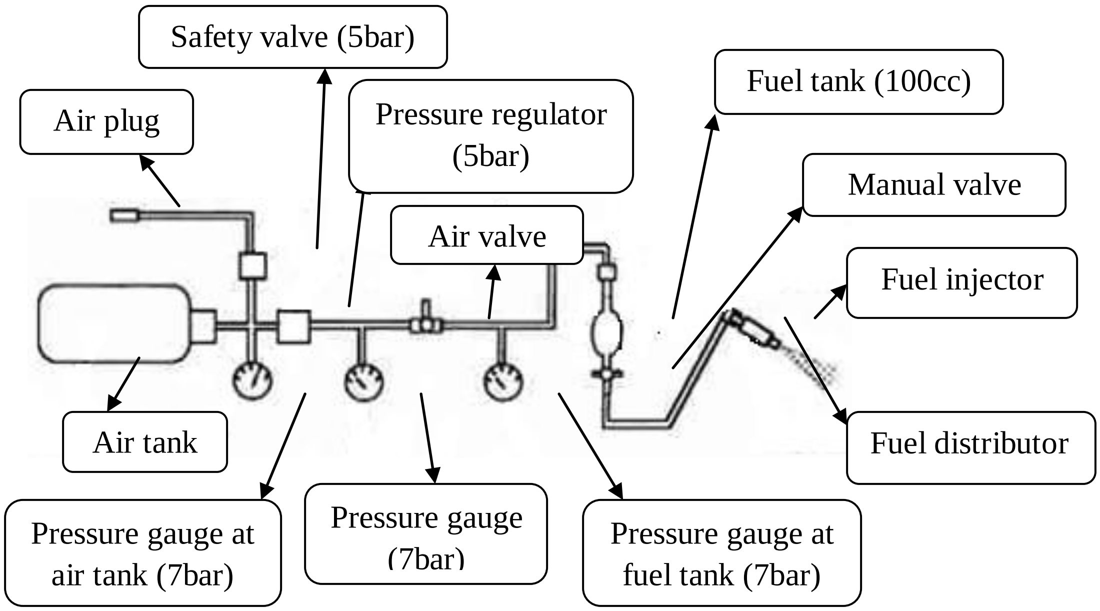


Figure 13: Fuel system [9] [11] [2]

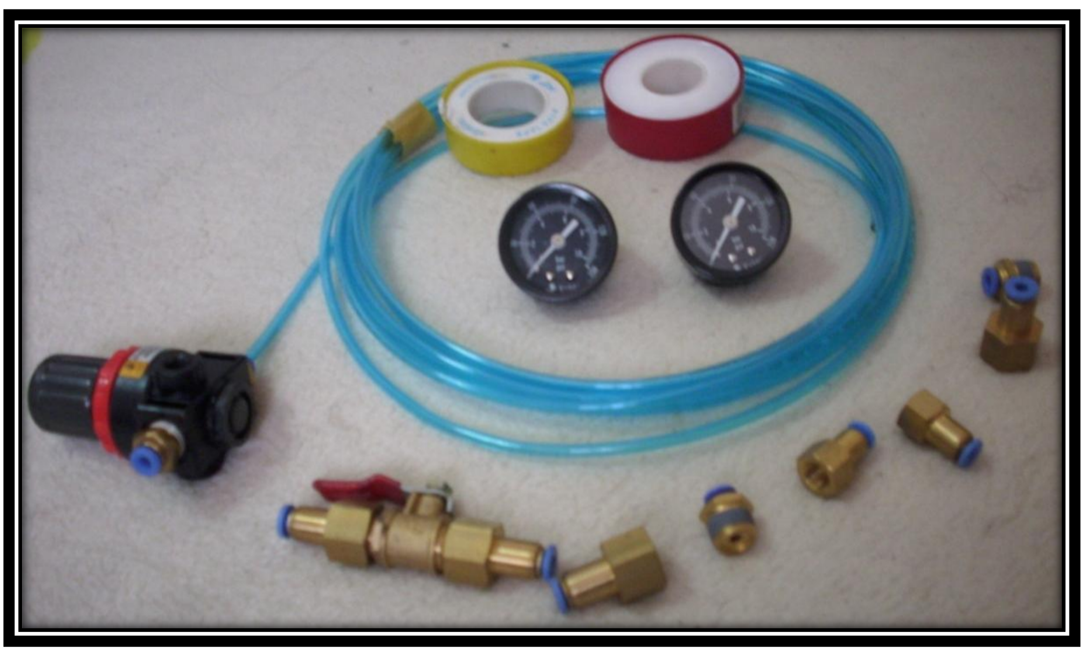


Figure 14: Fuel system equipments

Figure 15: Pressure gauge attach to temporary fuel tank

Figure 13 shows the fuel system for Shell Eco Marathon. The design is very simple and efficient to ensure the vehicle has low fuel consumption. The fuel system must not use electrical fuel pump as stated in the rules, so another option is to use mechanical pump in designing the fuel system [3]. Before come out with this design, researches from few teams had been made to identify the problem and difficulties that they had face during the competition. The main problem encounter is measuring the fuel during the competition due to heat expanding and vapor bubbles which strongly influences miss measuring of the fuel consumption [9].

The problem due to heat expanding of fuel is mostly solved by confirmation of air pressured electric fuel injection system without electric fuel pump that increases fuel temperature [17]. If it has only a few volume of fuel except tank in its whole fuel system, compensating of heat expanding by just fuel tank is almost accurate. The second problem due to miss measuring by vapor bubbles is very difficult to solve. The error happens when people open the fuel tank cap to measure the fuel consumption.

The same fuel vapor occurred by haste decompression in the fuel distributor although the manual valve of fuel tank is close due to some unexpected factors. Besides that, there are some volumes in fuel injector and fuel distributor that cannot be seen and certain on it amount of vapor bubbles with naked eye. For example, if the fuel consumption potential of the competition vehicle is 2000km/l and the distance travel is 15km, the real fuel consumption is 7.5cc. But if the remaining fuel vapor is 3cc that cannot be seen in the fuel distributor, the amount of fuel consumption measure is 4.5cc. Therefore, the record will be 3333(km/l). The error of fuel consumption measured is 67(%) [9].

The best solution on how to compensate these bubbles had been discussed and the most important point to improve it is after top up the fuel, do measure the temperature and depressurized. The in charge person will check the fuel level so it does not drop significantly where the significant drop is about 0-1mm, which is the usual drop when the system is compressed [9]. The procedure to top up fuel is explained under methodology.

During the competition, the fuel consumption by vehicle is calculated by weighing system. The fuel tank and fuel injector will be weight to determine the fuel consumes by vehicle and the total km/L will be obtained. Below is the picture of weighing system for fuel:

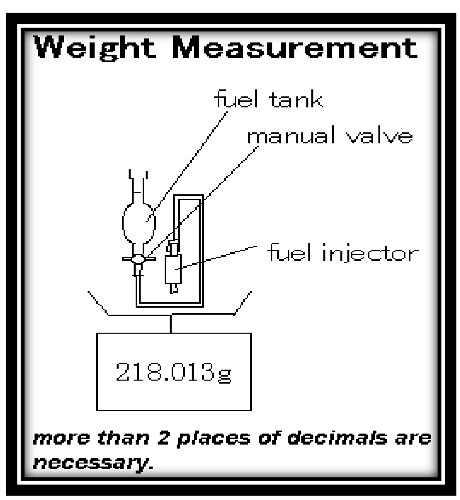
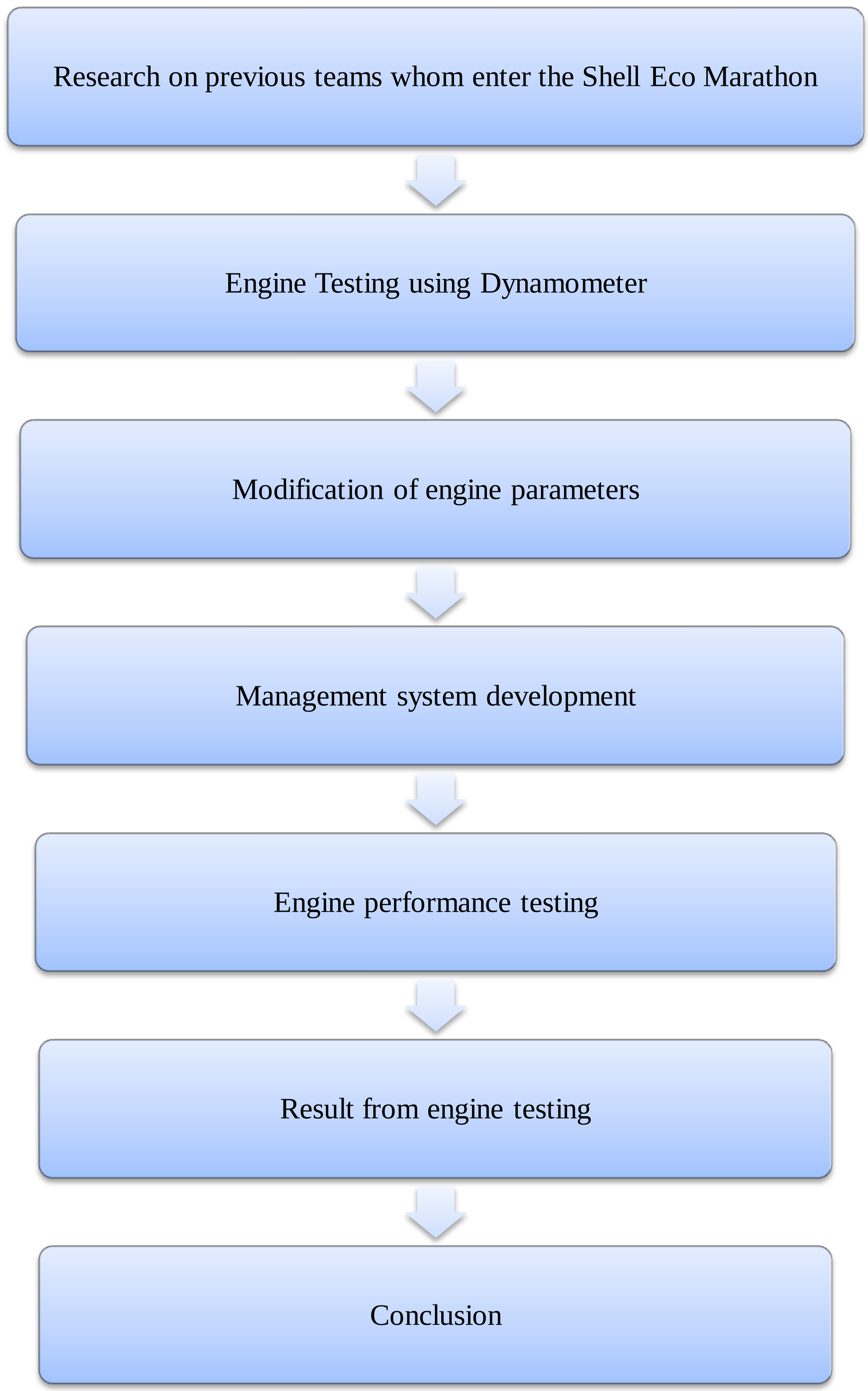


Figure 16: Weight measurement of fuel [9]

CHAPTER 3: METHODOLOGY

3.1 Specific Project Activities



	Dec	Jan	Feb	Mac	Apr	Mei	Jun	July
Research on previous teams whom enter Shell Eco Marathon	■	■	■	■	■	■	■	■
Engine testing using dynamometer								
▪ fabricate the coupler	■	■						
▪ fabricate engine mounting		■						
▪ integration of engine with test bed	■	■	■	■				
Modification of engine parameter								
▪ clutch and clutch cover				■	■			
▪ exhaust				■	■			
Management system development								
▪ EFI integration and tuning	■	■	■	■	■	■	■	■
▪ fuel system				■	■	■		
Engine performance testing								
▪ Engine testing procedure	■	■	■	■	■	■	■	■
▪ trial run			■	■	■	■	■	■
Result from engine testing								
▪ verification on manufacturer spec	■	■	■	■				
▪ verification after modification					■	■	■	■

Table 4: Project Timeline

3.2 Procedures

3.2.1 Calibrating the dynamometer torque meter procedure

Before each engine test:

The torque meter must be zeroed and calibrated before use. Follow the steps below:

1. Set the Span control to its maximum clockwise position.
2. Shake and rock the engine vigorously to overcome the stiction of the bearing seals. Vibration does this automatically when the engine is running.
3. Adjust the Zero control until the torque meter reads zero.
4. Check that the Zero is accurate by shaking the engine again
5. Hang a load of 3.5 kg on the calibration arm (J) of the dynamometer
6. Shake the engine until the torque meter reading settles down to a constant value
7. Adjust the Span control to give a torque reading of 8.6 Nm.
8. Remove the calibration load and repeat step (2) to (8) until satisfies that the Zero and Span settings are correct.

3.2.2 Engine testing procedure

To start the engine testing:

1. Advance the throttle or rack control to its maximum position
2. Note the maximum speed of the engine. (The dynamometer water flow should still be the trickle used for starting).
3. Keep the throttle or rack open and slowly adjust the needle valve to increase the flow of water through the dynamometer until the needle valve is fully open. Note the engine speed
4. Assume, for the time being, that the engine will be tested over the speed range just established. Choose at least five speeds between the two extremes at which to take readings of engine performance.

5. Keep the throttle open and reduce the water flow to a trickle, so that the engine returns to its maximum speed.
6. When the engine has settled down a steady output, record he readings of speed, torque, exhaust temperature and air consumption. Operate the fuel tap beneath pipette so that the engine takes its fuel from the pipette. Time the consumption of 8ml of fuel. Turn the tap so that the pipette again fills. For our engine, the pipette is not used since the engine has it own fuel tank.
7. Check the temperature of the water flowing out of the dynamometer is less than 80ºC. If the temperature is higher than this, increase the water flow to cool the dynamometer bearing seals.
8. Increase the flow of water into the dynamometer until the engine speed drops to the next highest selected value. Because the tome response of the dynamometer is fairly slow, the needle valve has to be operated slowly.
9. Allow time for the engine speed to stabilize before taking another set of results. If the dynamometer is too sensitive to obtain the desired speed, it will help if the drain tap is partially closed. Do not close fully
10. Repeat step (8) until the dynamometer needle valve is fully open.
11. Study the torque results. Engine normally produces a maximum torque at a certain speed. If your results suggest that the maximum is at a lower than you have reached, restrict the water flow from the dynamometer
12. Collect the testing data from dynamometer control unit measurement.

3.2.3 Fuel top up procedure

Below are the procedure for fuel top up at start line and finish line apply for pressurized fuel system:

At start line:

To speed up the procedure, it is recommended to come to start line and top-up with the fuel left in tank and a closed valve system after tank compressed to normal running pressure.

1. fuel is added well above the mark
2. system is compressed to the pressure marked on the meter
3. fuel valve is opened
4. start the engine, engine must be run until the fuel has dropped under the mark, to ensure the same pressure in the whole system as well as to uncover possible 'hide-ups' for fuel
5. valve is closed
6. tank is decompressed
7. fuel is added above the mark
8. temperature is measured
9. fuel will be leveled to mark with syringe
10. system is compressed to the pressure marked on the meter
11. valve is opened

After this procedure, the vehicle can move to the start line.

At the finish:

Competitor should not do anything to the vehicle until permission given.

1. valve is closed
2. decompression
3. fuel is topped up with motor-burette
4. temperature is taken
5. system is compressed
6. valve is opened
7. measurers will check that fuel-level does not drop significantly; significant drop is about 0-1mm, which is the usual drop when system is compressed.(measuring point of fuel tank I.D.is about 3mm)

3.2.4 EFI Controller procedure

The EFI controller and throttle body function user manual is attached in **APPENDIX A**

3.3 Equipment / Tools Used

3.3.1 Dynamometer

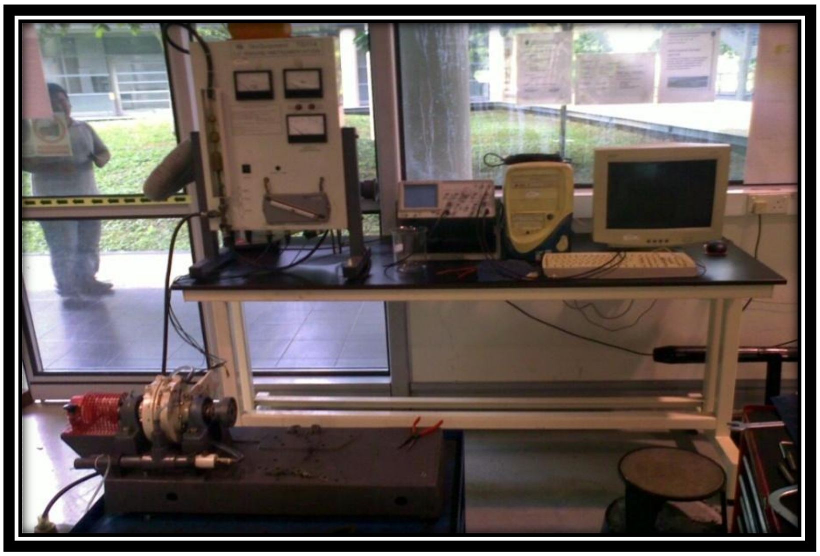


Figure 17: Dynamometer

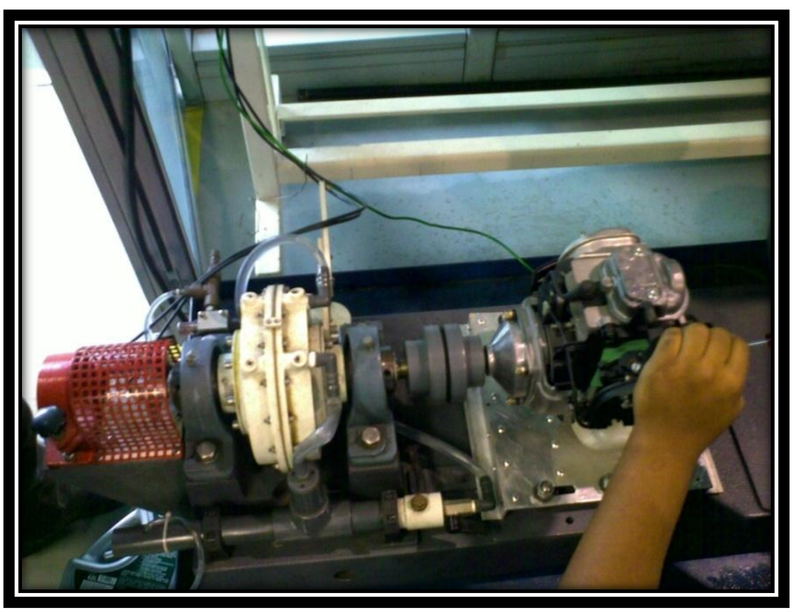


Figure 18: Engine mounting at dynamometer

A dynamometer or "dyno" for short is a device for measuring force, moment of force (torque), or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (rpm) [12]. A dynamometer consists of an absorption (or absorber/driver) unit, and usually includes a means for measuring torque and rotational speed. An absorption unit consists of some type of rotor in housing. The rotor is coupled to the engine or other equipment under test and is free to rotate at whatever speed is required for the test and provide braking torque between dynamometer's rotor and housing. The means for developing torque can be frictional, hydraulic, electromagnetic and many more according to the type of absorption or driver unit [12]. Dynamometers are useful in the development and refinement of modern day engine technology. The concept is to use a “dyno” to measure and compare power transfer at different points on a vehicle, thus allowing the engine or drive train to be modified to get more efficient power transfer.

3.3.2 Throttle Position Sensor (TPS)

A throttle position sensor (TPS) is a sensor used to monitor the position of the throttle in an internal combustion engine. The sensor is usually located on the butterfly spindle so that it can directly monitor the position of the throttle valve butterfly [13]. The sensor is a potentiometer, and therefore provides a variable resistance dependent on the position of the valve and hence throttles position. The sensor signal is used by the engine control unit (ECU) as an input to its control system. The ignition timing, fuel injection timing and other parameters are altered depending upon the position of the throttle, and also depending on the rate of change of that position [13]. In our EFI system, the throttle body is using ball valve to enhance the air flow so the TPS control the position of opening ball valve which is equal to the air enter the engine.

Figure 19: Throttle Position Sensor (TPS) [9]

3.3.3 Optical Encoder

Optical encoder is typically uses a light source shining through, or reflecting off, an optical disk with lines or slots that interrupt the beam of light to an optical sensor 15]. Electronics count the interruptions of the beam and generate the encoder's output pulses. It is used to detect the engine position and speed in the car. In our alpha –N system, the optical encoder is detect when the beam sensor reflect to the signal disk. The speed in the car will be detect and display in the controller. Below is the picture on how the optical encoder works:

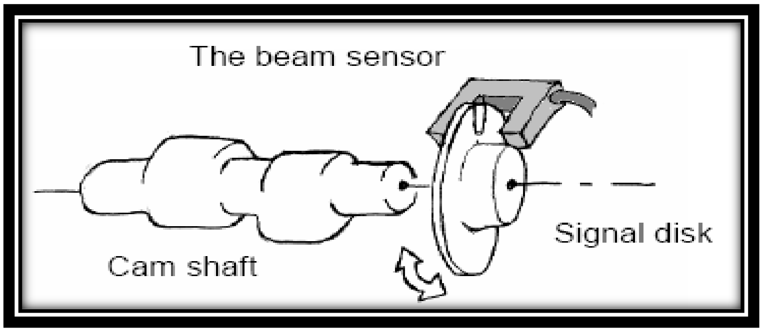


Figure 20: Optical encoder [9]

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Engine Mounting and coupler for engine testing

The current dynamometer available for small engine in Universiti Teknologi PETRONAS comes along with the engine mounting and coupler for testing engine. The measurement and position of engine mounting and coupler cannot fix with Honda GX 35. Due to this problem, the new engine mounting and coupler need to be fabricated before start the engine testing.

The engine mounting is made from 3mm aluminum with dimension of 25cm x 27cm to ensure it can support the engine to align with the coupler and reduces the vibration during engine testing. It is build to raise the engine to appropriate level so that the engine can be directly coupled via the clutch to the dynamometer [11]. During engine testing, the rubber matt about 2mm thick is used to reduce vibration since four stroke single cylinder engine has high vibration. Below is the picture of engine mounting:

Figure 21: Engine mounting

Coupler is made to connect the engine with dynamometer and to ensure the engine and dynamometer is align. The miss align of coupler between engine and dynamometer will bring danger as the engine will disconnect from engine or dynamometer and spin during the engine testing [18]. Due to this reason, the coupler design must be suitable for dynamometer and accurately measure. The design will also help in term of reducing vibration during engine testing. The coupler is attached to magneto during engine testing since the dynamometer has high load if it attach with the clutch system. Previously, when the coupler is attached with clutch, the clutch is slip and the engine cannot be tested in high RPM due to friction. Below is the picture of coupler between engine and dynamometer:

Figure 22: Coupler

Below is the picture of engine installed in the vehicle

Figure 23: Engine installation in vehicle

Figure 24: Vehicle

4.2 Exhaust length

The other modification made is the exhaust length. The calculation for exhaust is dependent on engine RPM and gas flow temperature. Thus, the engine can only be tuned for one specific engine RPM, unless a variable length manifold is used. Design for the Honda GX 35 engine was difficult because the engine designed to run over a broad RPM range [11]. Therefore, engine speed of 5500 RPM was chosen since the engine idles is at 1800 RPM. Besides that, 5500 RPM to 6000 RPM is where the Honda GX 35 obtains its best efficiency, while the exhaust temperature was measured to reach a maximum temperature of 350 ºC (623.15 K). Thus, the calculation for exhaust length is as below:

Exhaust Length [11]:

$$L = 10 \times c / (RPM)$$

Where [11]:

c = speed of sound at given temperature (m/s)

RPM = revolutions per minutes of the engine

$$c = \sqrt{k \times R \times T}$$

k = specific heat ratio = 1.4

R = air ideal gas constant = 287

T = temperature of the flow (in Kelvin)

Thus, the exhaust length is **<u>0.909 m</u>**. The exhaust length calculation is in **APPENDIX B**

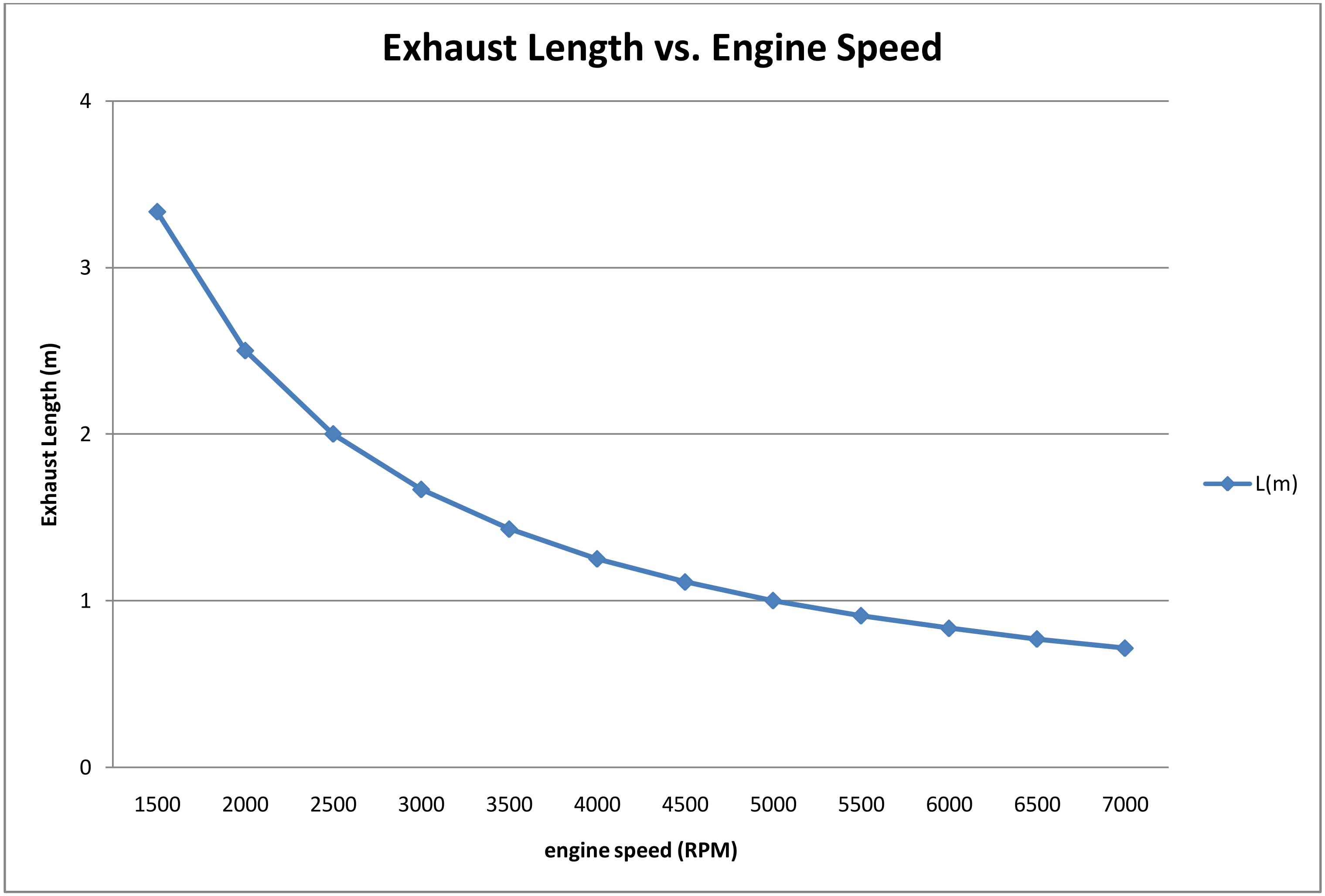


Figure 25: Exhaust Length versus Engine Speed

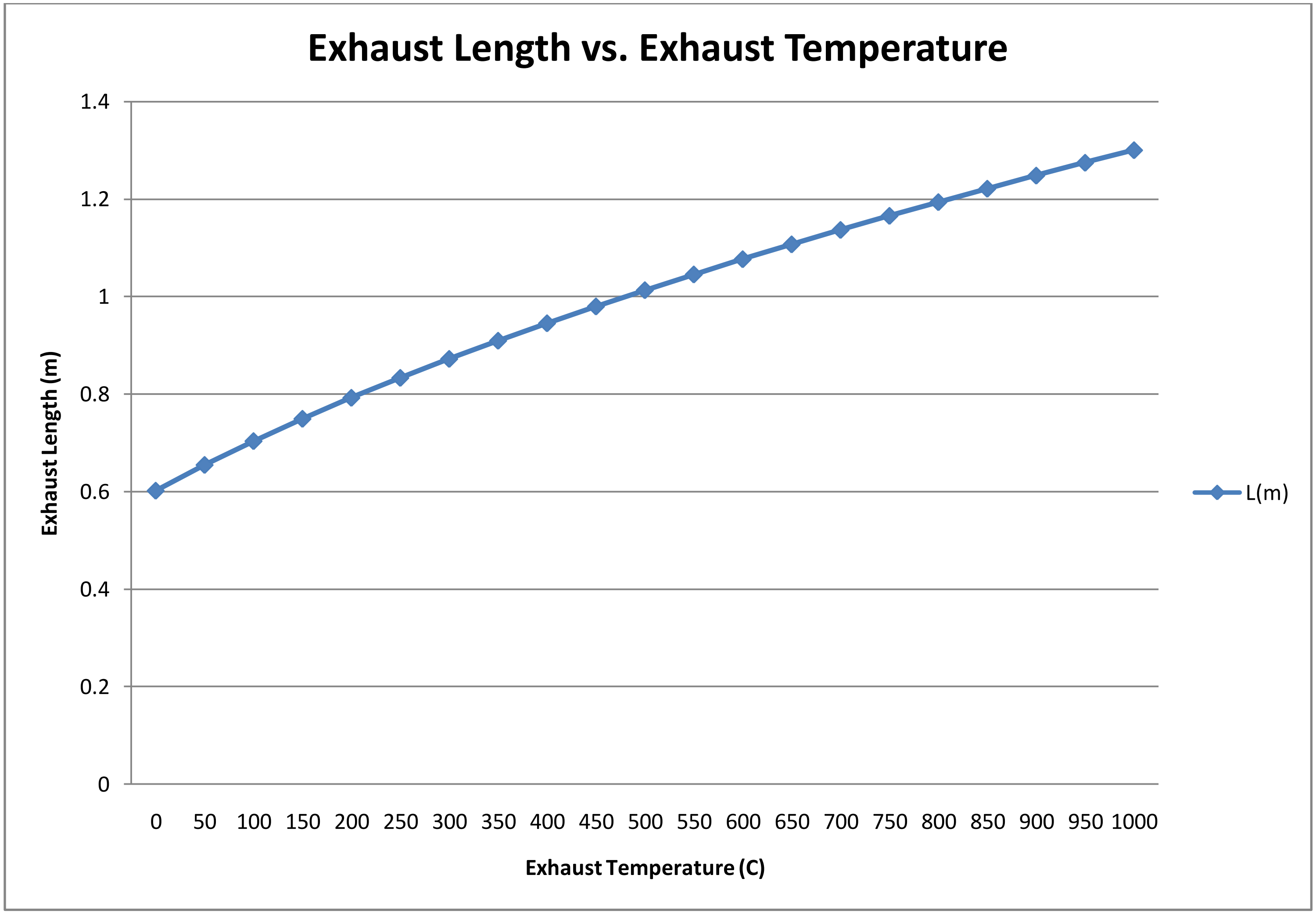


Figure 26: Exhaust Length versus Exhaust Temperature

4.3 Carburetor to Electronic Fuel Injection (EFI) engine.

The major modification on HONDA GX 35 is converting the engine from carburetor to Electronic Fuel Injection (EFI) to enhance it fuel consumption. The result for both carburetor engine and EFI engine are determined in term of torque, power, fuel efficiency and fuel measure. The result of fuel efficiency is given in brake specific fuel consumption (bsfc) during engine testing and the result for fuel measure is obtained during trial run. Brake specific fuel consumption (bsfc) is a measure of an engine's efficiency. It is the rate of fuel consumption divided by the power produced. BSFC is specific for shaft engines such as reciprocating engine.

Below is the result for carburetor engine in term of torque, power bsfc and fuel measure in km/L. The result is given until 5500 rpm in both engines testing since the dynamometer available only has a maximum speed of 6000 rpm. Due to safety reason, the data collected at only 5500 rpm where the best efficiency of the engine.

The calculation to convert Torque into Power in horse power (HP) is defined by:

$$\text{Power (HP)} = (\text{Torque} \times \text{Engine speed}) / 5{,}252$$

The calculation for bsfc is defined by:

$$\text{BSFC} = \text{Fuel rate} / \text{Power}$$

Where:

Fuel rate is the fuel consumption in grams per hour (g/hr)

Power is the power produced in Kilowatts where $kW = w * T / 9549.27$

w is the engine speed in rpm

T is the engine torque in Newton meter (N·m)

*Note: The **Power** in the BSFC calculation is not weather corrected*

The results for carburetor engine is attached in **APPENDIX C**

Below is the result for EFI engine in term of torque, power bsfc and fuel measure in km/L. The result is given until 5500 rpm in both engines testing since the dynamometer available only has a maximum speed of 6000 rpm. Due to safety reason, the data collected at only 5500 rpm where it is the best efficiency of the engine.

The calculation to convert Torque into Power in horse power (HP) is defined by [21]:

$$\text{Power (HP)} = (\text{Torque x Engine speed}) / 5{,}252$$

The calculation for bsfc is defined by [21]:

$$\text{BSFC} = \text{Fuel rate} / \text{Power}$$

Where:

Fuel rate is the fuel consumption in grams per hour (g/hr)

Power is the power produced in Kilowatts where $kW = w * T / 9549.27$

w is the engine speed in rpm

T is the engine torque in Newton meter (N·m)

*Note: The **Power** in the BSFC calculation is not weather corrected*

The results for EFI is attached in **APPENDIX D**

By converting the engine from carburetor to electronic fuel injection, the torque, power, bsfc and fuel measure of engine is improved. The improvement of fuel consumption from carburetor to EFI is about 50% of the original results. Below is the comparison graph for torque, power, bsfc and fuel measure (km/L) between carburetor and EFI engine.

The result of engine testing and trial run is obtained and analyze at 5500 rpm and approximately 35 km/h where it is the engine speed used during competition. The detail explanation is given below according to it torque, power, bsfc and fuel measure.

From figure 27, the torque of engine after converting from carburetor to electronic fuel injection is increased from 1.5 Nm to 2 Nm. The improvement of engine torque will increase the performance of engine during operation. The improvement of engine torque will improve the work output of engine to drive train.

From figure 28, the engine power is increase from 1.6 HP to 2 HP. This improvement will help the engine performance by producing the high work output to move the vehicle. The increment in engine power will help to reduce the fuel consumption used by the engine during operation.

From figure 29, the engine bsfc is increase from 300 g/KW.h to 500 g/KW.h. This improvement shows that the efficiency of engine is increase from its original engine. This improvement will help to reduce the fuel consumption of engine since the fuel used by engine during operation is low compare to before. This improvement is the biggest help in improving the fuel consumption

From figure 30, the km/L versus km/h is increase from 500km/L to 1125 km/L at 35 km/h. The increment in km/L is due to the installation of electronic fuel injection where the fuel injected to engine can be adjusted. The engine control unit (ECU) is the controller used to set the fuel injected in engine respected to it valve timing.

In conclusion, the engine improvement after converting carburetor to electronic fuel injection is increased about 50 %.

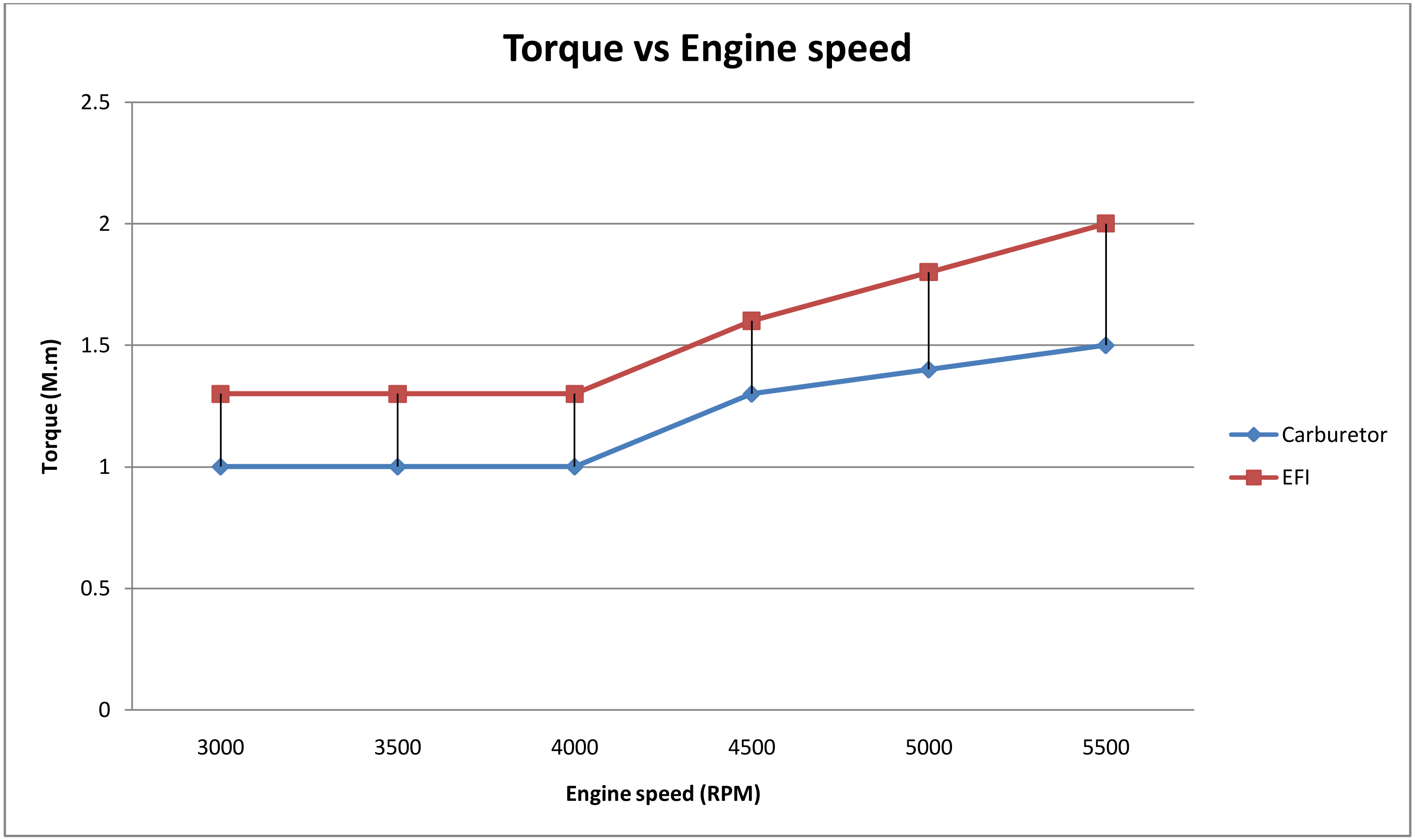


Figure 27: Graph torque versus engine speed between carburetor and EFI

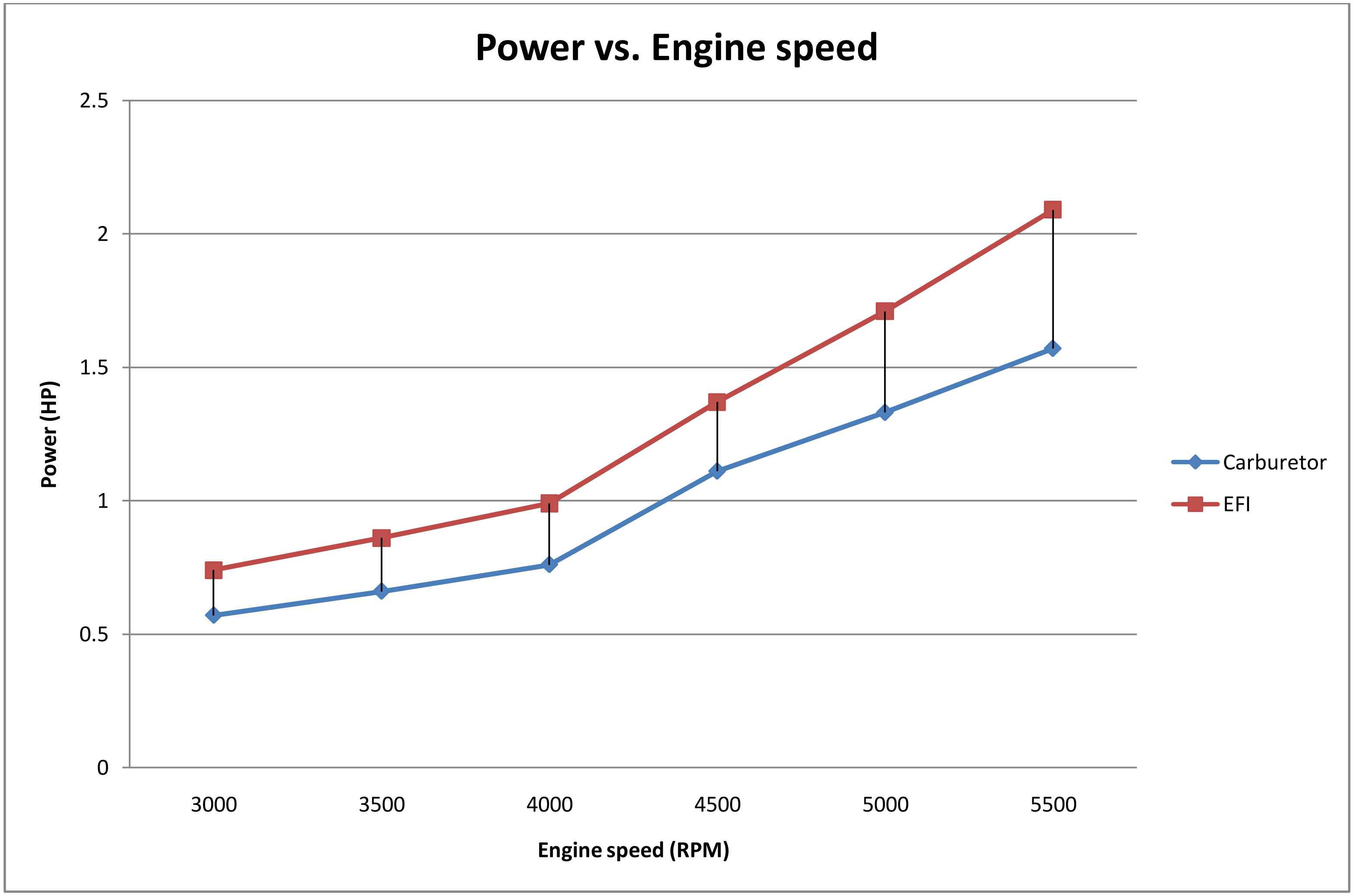


Figure 28: Graph Power versus Engine speed between carburetor and EFI

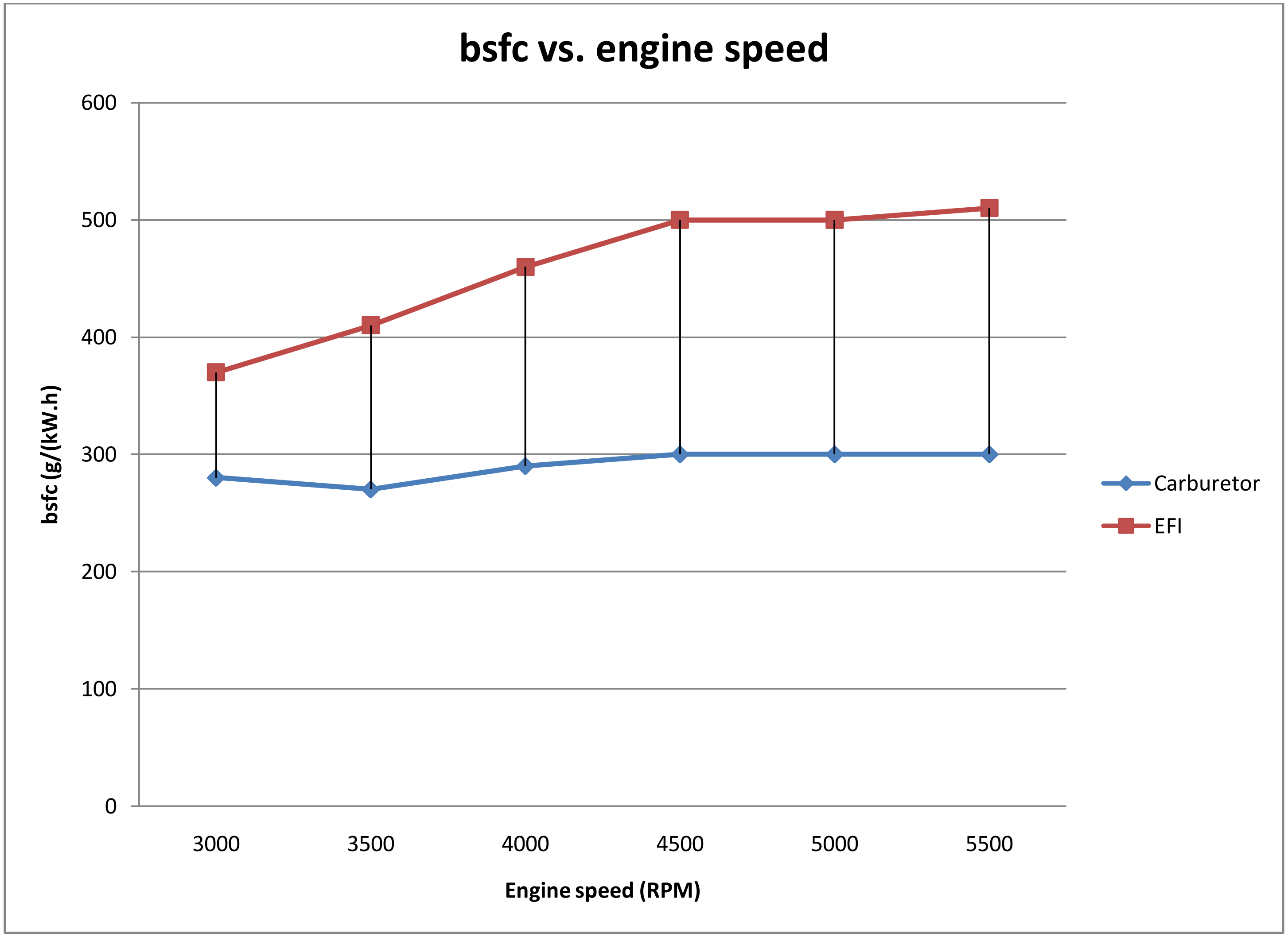


Figure 29: Graph bsfc versus engine speed between carburetor and EFI

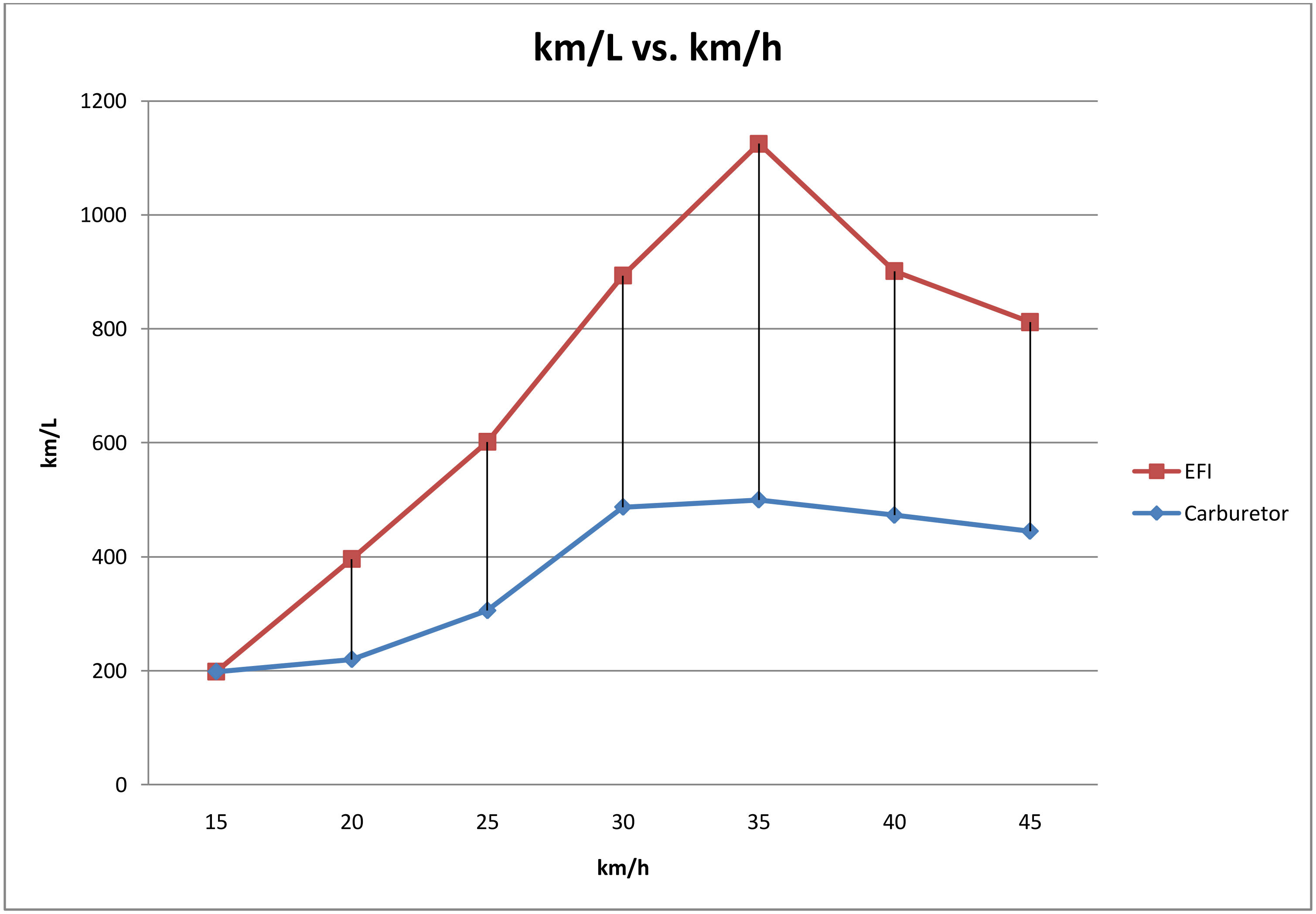


Figure 30: Graph km/L versus km/h between carburetor and EFI

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Recommendation

One of the improvements that can be made to enhance the fuel consumption of vehicle is improving the valve timing by replacing one cam to two cams for each intake and exhaust valves so the valve timing for each valve can be set differently according to engine performance. In most of the combustion engines, the mixture of fresh air and fuel enter cylinder when valve is opened and closed by a rotation cam [20].

The cam is composed of two main parts which are the base circle and the lobe. The base circle is the part of the cam where the valves are totally closed. The lobe composed of the opening and closing sides enabled the valve to be lifted and pushed down. The system of distribution is composed of the cam, a pushrod or follower, a rocker arm, a spring and the valve.
The pushrod is lifted by the lobe of the cam and via the rocker arm and it pushes down the valve that is opened so the air and fuel can now fill the cylinder [20].

Then, as the cam continues its rotation, the follower arrives on the closing side. The follower is taken down and the spring closes the valve. The same process is used for the opening and the closing of the two valves. In fact, the rotation movement of the cam is transformed into a translation movement for the opening and closing of the valve. Usually, each valve has its own cam that opens and closes it. But, Honda GX 35 engine has only one cam which opens and closes the two valves. To optimize the amount of fuel air mixture in cylinder and thus reduce the consumption, the engine needs to be replaced from one cam to two cams [20]. Each valve would be opened and closed with different angles where its own cam that will be designed specifically.

Below is the picture on how the cam controls the valve timing in Honda GX 35:

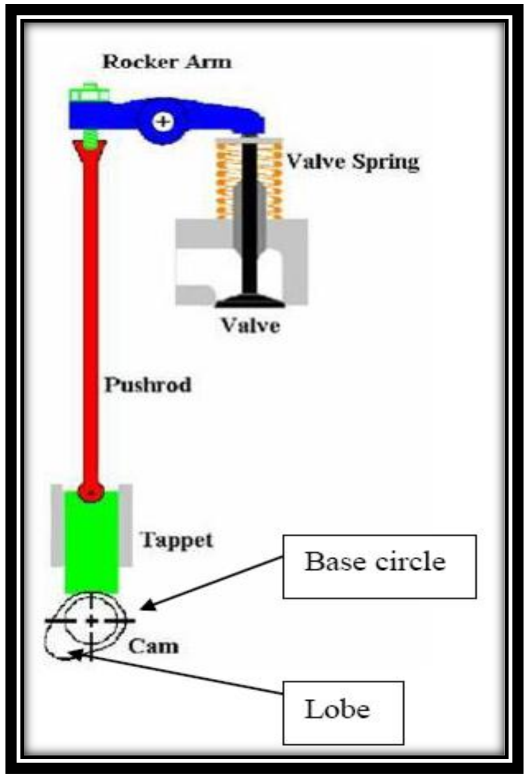


Figure 31: cam and valve in Honda GX 35 [20]

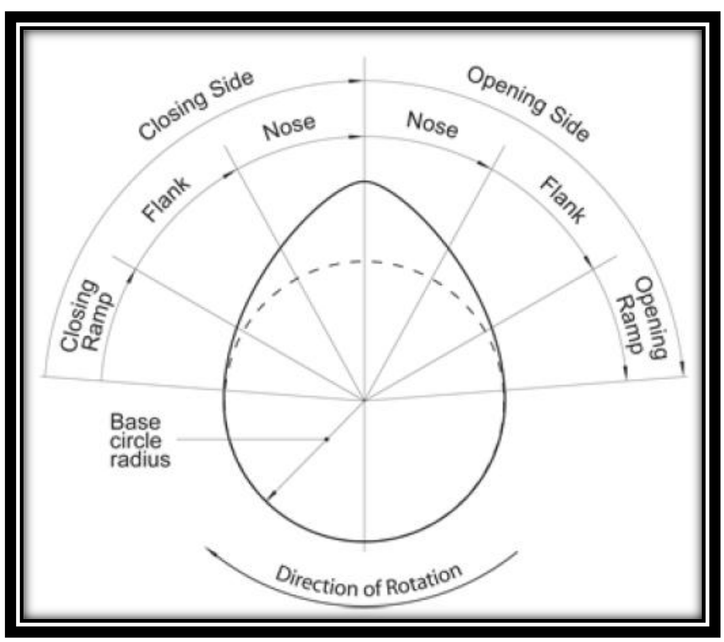


Figure 32: Designing the cam in term of angles [20]

Designing two cams for engine to control the valve timing will helps the engine to achieved Atkinson cycle. The transformation of the engine from the Otto cycle to the Atkinson cycle can be made easily [19]. The interest of this cycle is to have a compression ratio smaller than the expansion ratio. The admission and exhaust stroke are the same as the Otto cycle.

During the compression stroke, the inlet valve is held opened longer than with the Otto cycle [19]. So the fresh air escapes the cylinder and goes into the intake manifold rather than being compressed when the piston is going from the BDC to the TDC. As a part of the mixture has been repressed, only a fraction of the air is compressed when the inlet valve is closed. The air volume is expanded beyond the volume when compression began. So we obtained a reduced compression while the expansion stroke stays unchanged. It allows more energy converted from heat to useful mechanical energy [20]. The engine is more efficient.

Nevertheless, the Atkinson cycle reduces power density compared to the Otto cycle [20]. Indeed, an Atkinson cycle engine does not take as much air as it would be with a similar Otto cycle engine [20]. This cycle could be used for the engine since it's easily applicable and does not require too important changes on the engine. Below are the Atkinson cycle and its improvement:

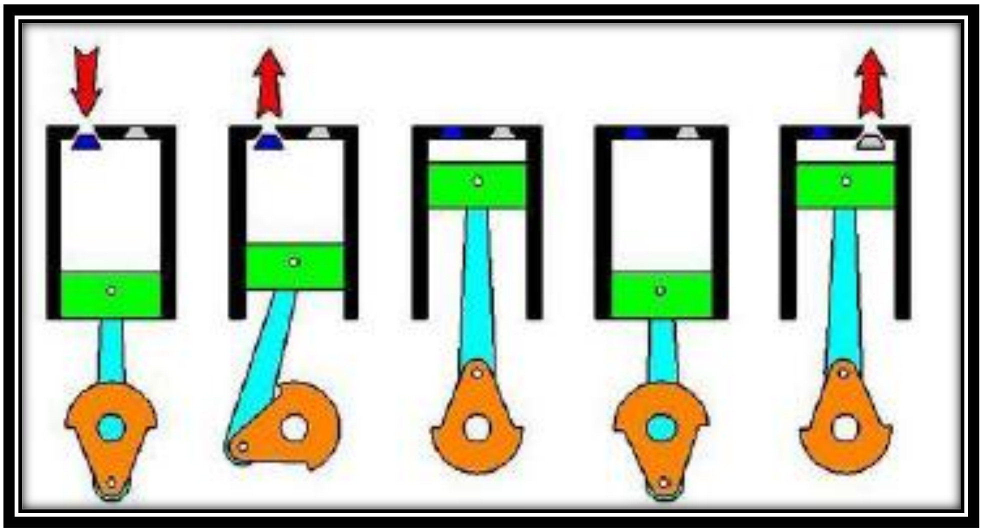


Figure 33: Atkinson cycle [19]

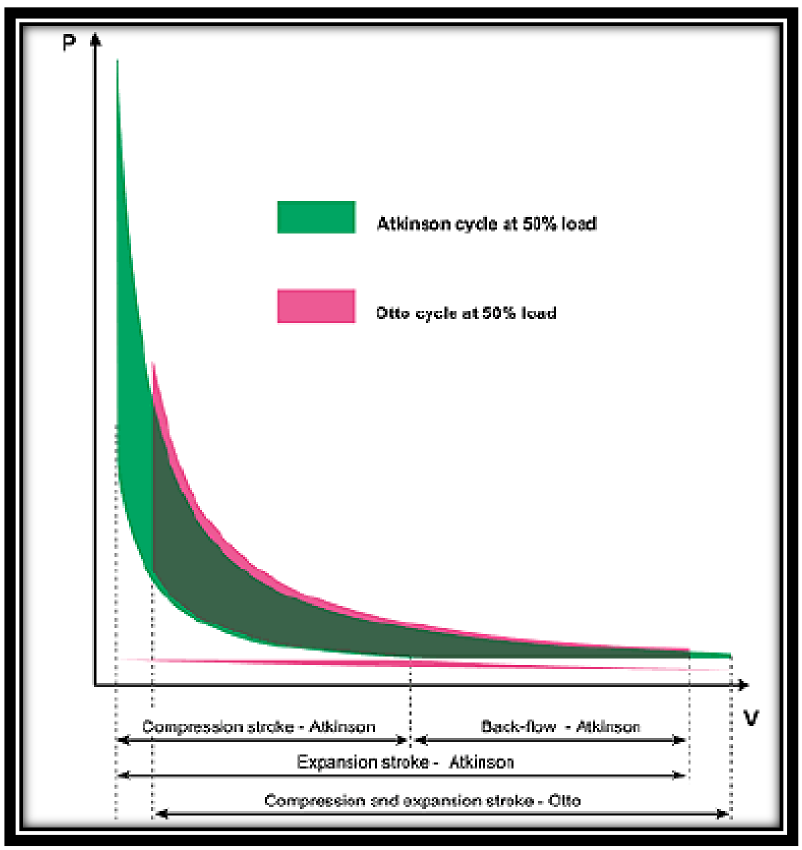


Figure 34: Atkinson graph cycle [19]

5.2 Conclusion

In conclusion, the application of alpha-N system and some modification on exhaust length will able our vehicle uses the least amount of fuel to travel the farthest distance. The installation of alpha – N system is a major improvement in fuel consumption for the engine. The improvement in term of torque, power and bsfc is about 50% from the original results obtained from carburetor engine. The total km/L after converting the carburetor to EFI is from 500km/L to 1125 km/L. Due to time constraint and availability of equipment, the EFI system installed is not fully fine tune with the engine. Thus, it shows that the km/L can still be improved by varies and manipulate the data to achieve the highest km/L. Besides that, the modification on exhaust length helps to improve the air flow and volumetric efficiency of the engine since it provides the low pressure at the exhaust valve to help the exhaust gas out of cylinder [11]. The modifications made to the engine is referred to the previous team enter Shell Eco marathon and perform successfully during the competition. Moreover, there are some modifications can be made such as increase the compression ratio, improving the exhaust part and many more [20]. Research is continues process that need to be done to more teams to ensure the best application made on the engine and successfully work during the competition. The objective of this project is achieved with the improvement in km/L of the vehicle when carburetor is converted to EFI system. It is proven that EFI enhance the fuel consumption of vehicle.

REFERENCES

[1] Cal Super Mileage Vechile Engine Displacement Reduction and Electronic Fuel Injection Final Report from University of California, Berkeley, 2004

[2]http://www.ecs.umass.edu/mie/smv/2004_2005_Page/index.htm

[3] http://www.shell.com/home/content/ecomarathon/asia/

[4] Crouse Anglin, 1993, *Automotive Mechanics Tenth Edition*, McGraw Hill International Editions

[5] http://www.fueleconomy.gov/feg/why.shtml

[6] GX 35 sells broucher

[7] http://www.ckmcgraw.com/afmcgraw/smv.htm

[8] http://www.bayareamotorsport.com/alphan.html

[9] http://fancycarol.free.fr/index.htm

[10] http://poisson.me.dal.ca/~dp_08_14/Frame.html

[11] Supermileage Team Final Report from Dalhousie University, 2008

[12] http://en.wikipedia.org/wiki/Dynamometer

[13] http://en.wikipedia.org/wiki/Throttle_position_sensor

[14] http://www.honda-engines.com/engines/gx35.htm

[15] http://en.wikipedia.org/wiki/Rotary_encoder

[16] Ganesan, V., *Internal Combustion Engines Second Edition*, Tata McGraw-Hill, New Delhi, 1999.

[17] Study of Electronic Fuel Injection Application to the carburetor Single Cylinder Four Stroke Engine from Universiti Teknology PETRONAS, 2009

[18] EFFECT OF ENGINE PERFORMANCE FOR FOUR-STROKE ENGINE USING SIMULATION by Rosli Abu Bakar, Semin, Abdul Rahim Ismail from Automotive Focus Group, Faculty of Mechanical Engineering, University Malaysia Pahang

[19]http://en.wikipedia.org/wiki/Atkinson_cycle

[20] Industrial Placement Report: Improvement of Distribution System for Shell Eco Marathon from NEWI University in Wrexham

[21] http://www.worldlingo.com/ma/enwiki/en/Brake_specific_fuel_consumption

[22] http://www.iutsupermileage.com/2010_01_01_archive.html

APPENDICES

APPENDIX A

Alpha- N system user manual

APPENDIX B

Exhaust length data, where temperature is 623.15 K at constant speed of 5500 RPM.

Exhaust length versus engine speed

RPM	c(m/s)	L(m)
1500	500.381524	3.3358768
2000	500.381524	2.5019076
2500	500.381524	2.0015261
3000	500.381524	1.6679384
3500	500.381524	1.4296615
4000	500.381524	1.2509538
4500	500.381524	1.1119589
5000	500.381524	1.000763
5500	500.381524	0.9097846
6000	500.381524	0.8339692
6500	500.381524	0.7698177
7000	500.381524	0.7148307

Table 5: Exhaust length versus engine speed data

Exhaust length versus exhaust temperature

Temp in C	Temp in K	c(m/s)	L(m)
0	273.15	331.2879	0.602342
50	323.15	360.3355	0.655155
100	373.15	387.21011	0.704018
150	423.15	412.33684	0.749703
200	473.15	436.01797	0.79276
250	523.15	458.47756	0.833596
300	573.15	479.88714	0.872522
350	623.15	500.38152	0.909785
400	673.15	520.06891	0.94558
450	723.15	539.03773	0.980069
500	773.15	557.36135	1.013384
550	823.15	575.10144	1.045639
600	873.15	592.31045	1.076928
650	923.15	609.03339	1.107333
700	973.15	625.30926	1.136926
750	1023.15	641.17211	1.165767
800	1073.15	656.65186	1.193912
850	1123.15	671.77501	1.221409
900	1173.15	686.56512	1.2483
950	1223.15	701.04327	1.274624
1000	1273.15	715.2284	1.300415

Table 6: Exhaust length versus exhaust temperature data

APPENDIX C

Below is the data collected for carburetor engine:

Engine testing results

Engine speed (rpm)	Torque (Nm)	Power (HP)	Fuel rate (g/hr)	bsfc (g/kW.h)
3000	1	0.57	87.96	280
3500	1	0.66	98.96	270
4000	1	0.76	121.47	290
4500	1.3	1.11	183.78	300
5000	1.4	1.33	219.91	300
5500	1.5	1.57	259.18	300

Table 7: Engine testing result for carburetor engine

Trial run results

km/h	km/L
15	198.3
20	219.8
25	305.6
30	487.5
35	500.1
40	473.2
45	445.1

Table 8: Trial run results for carburetor engine

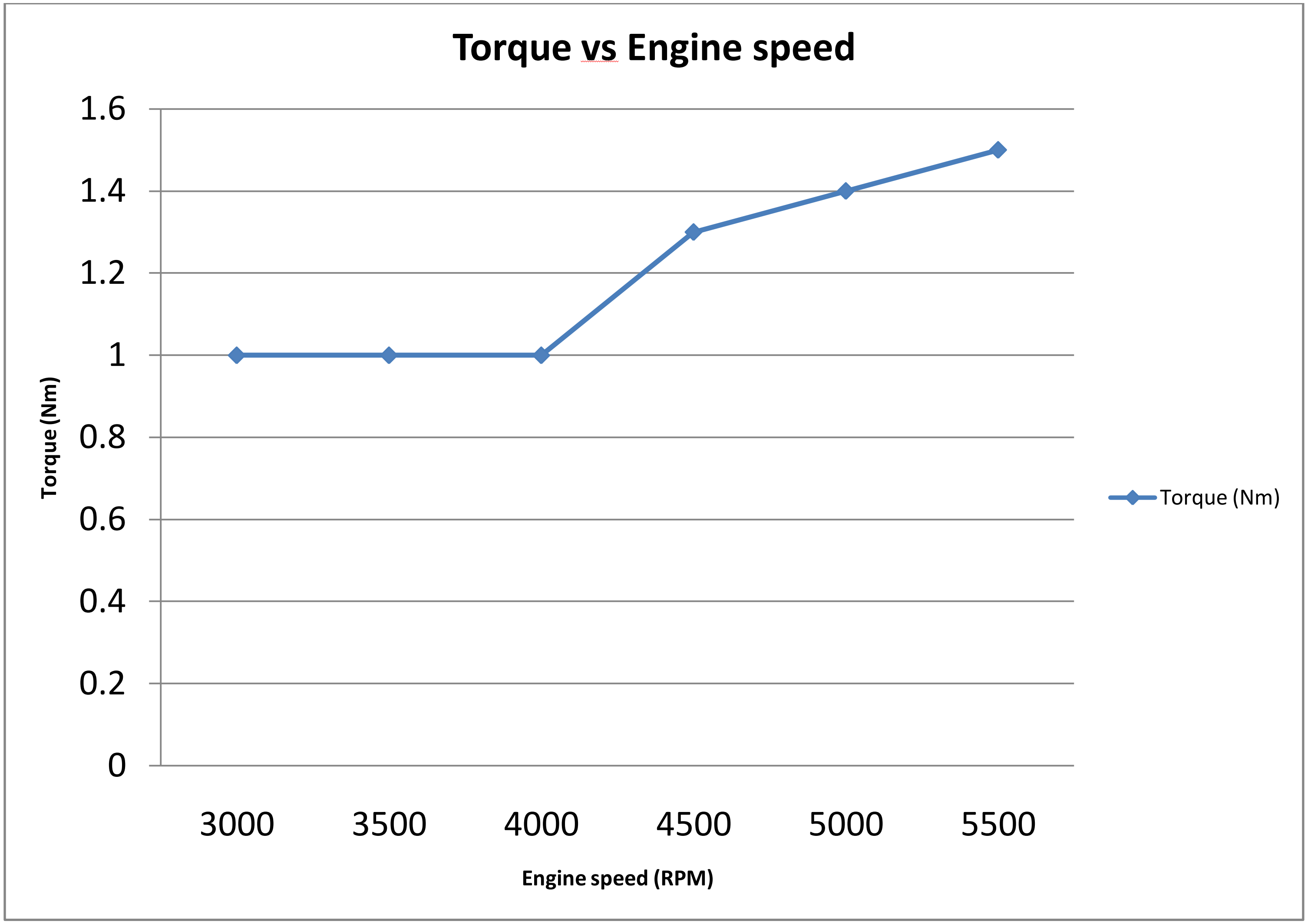


Figure 35: Graph torque versus engine speed for carburetor engine

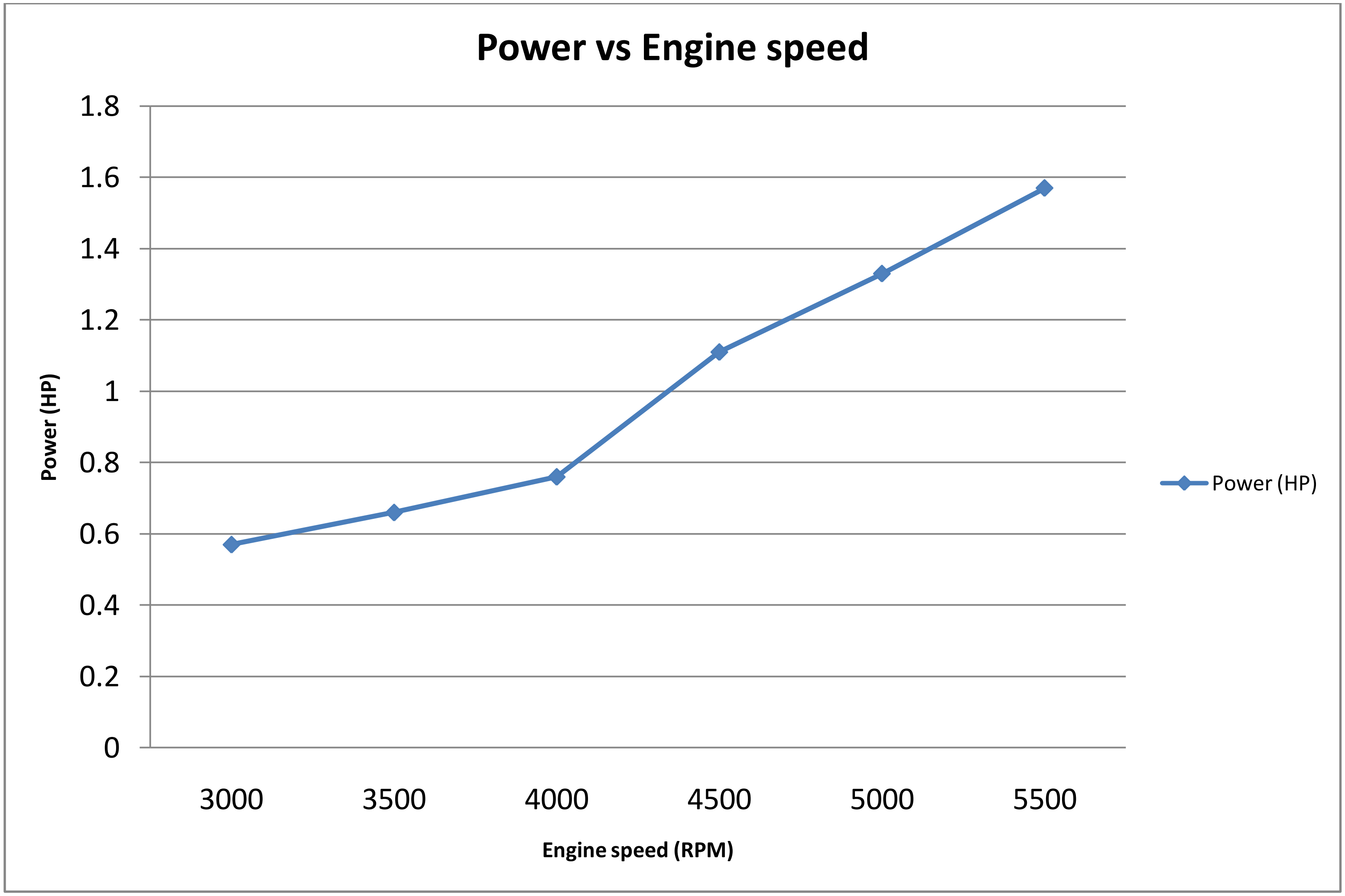


Figure 36: Graph power versus engine speed for carburetor engine

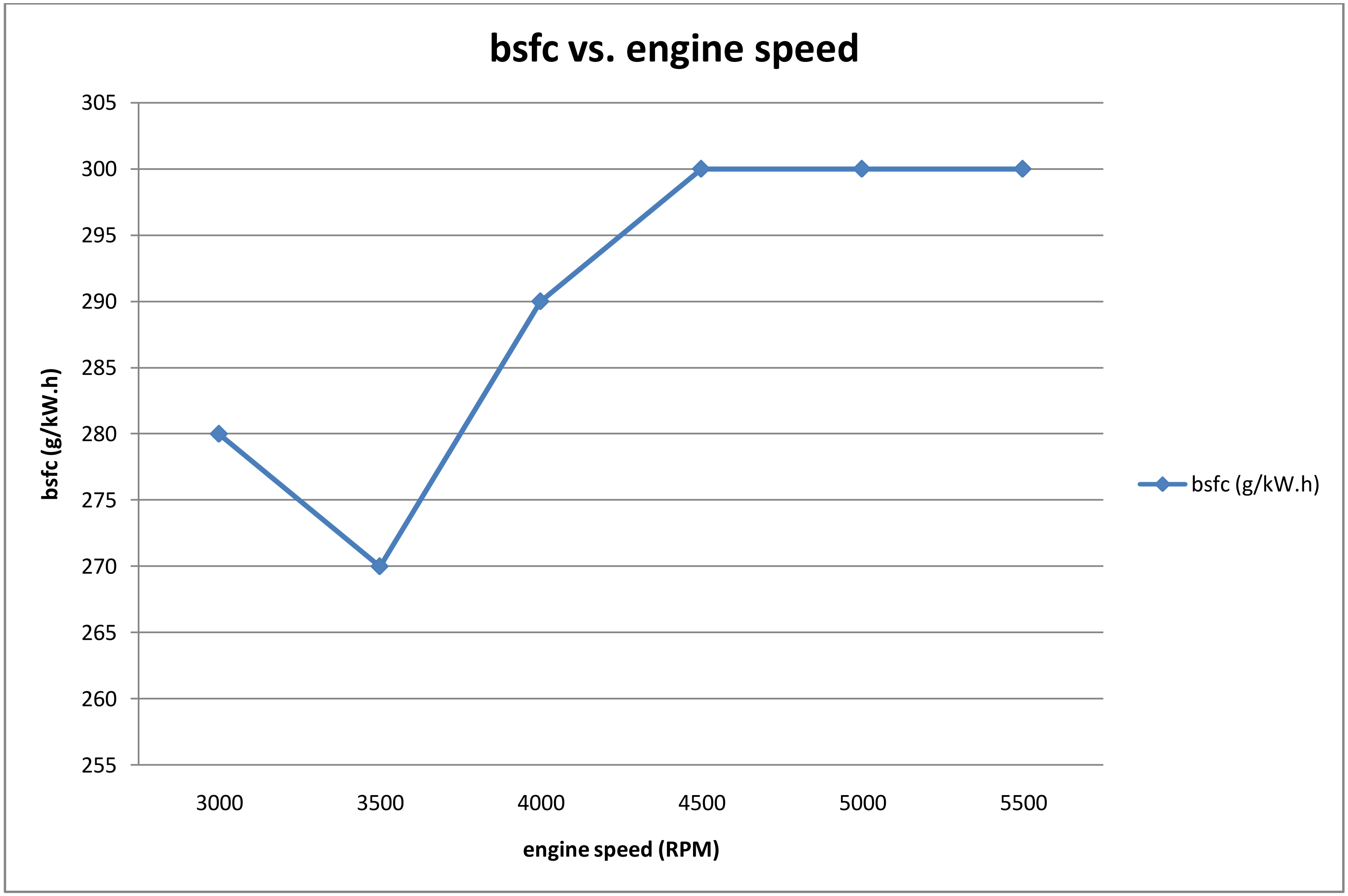


Figure 37: Graph bsfc versus engine speed for carburetor engine

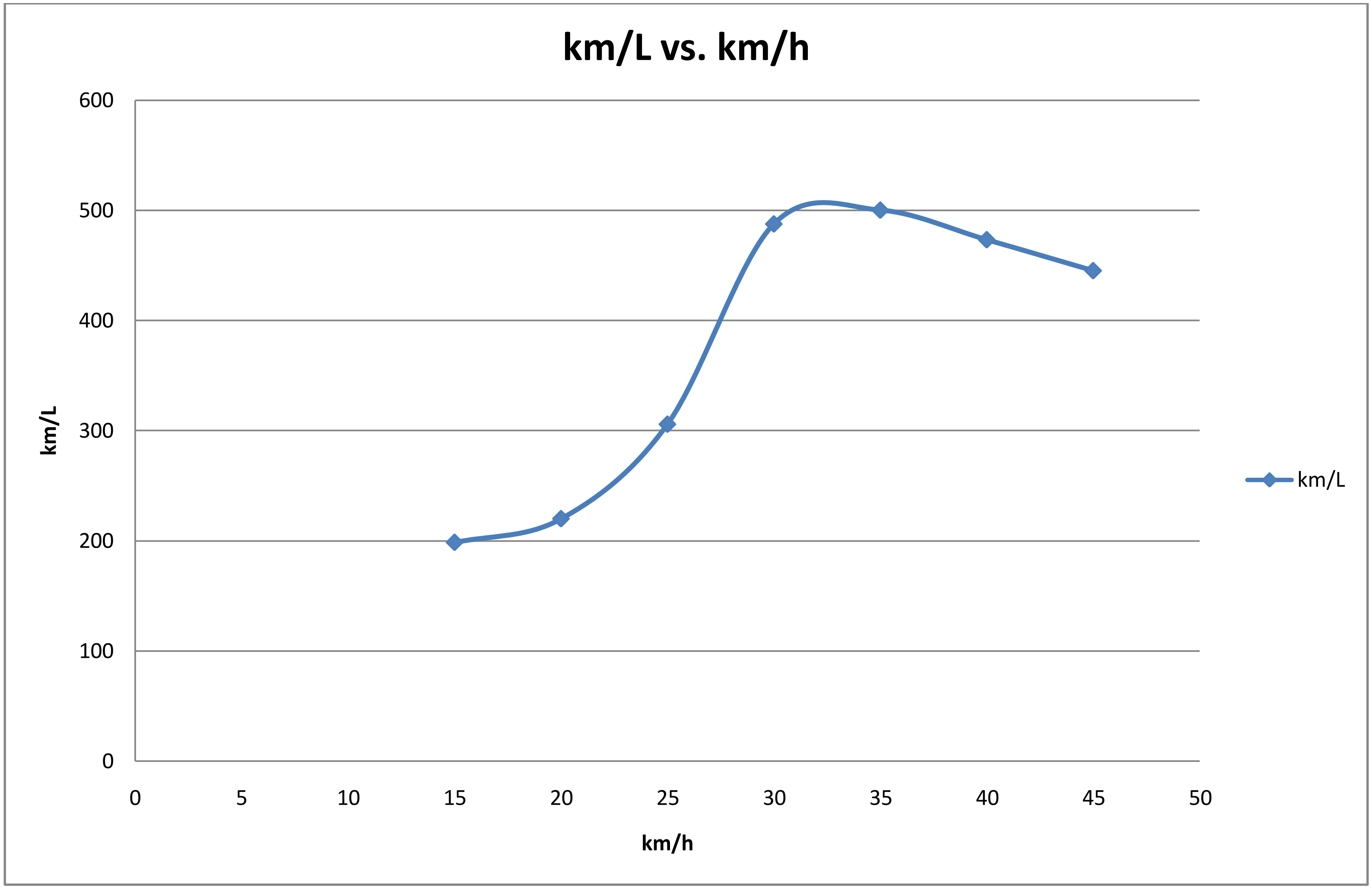


Figure 38: Graph km/L versus km/h for carburetor engine

APPENDIX D

Below is the collected data for EFI engine:

During engine testing

engine speed (RPM)	Torque (N.m)	Power (HP)	fuel rate (g/hr)	bsfc (g/kW.h)
3000	1.3	0.74	151.11	370
3500	1.3	0.86	195.36	410
4000	1.3	0.99	250.49	460
4500	1.6	1.37	376.99	500
5000	1.8	1.71	471.24	500
5500	2	2.09	587.48	510

Table 9: Engine testing result for EFI engine

During trial run

km/h	km/L
15	198.3
20	396.1
25	601.9
30	893.7
35	1125.3
40	901.5
45	812.3

Table 10: Trial run results for EFI engine

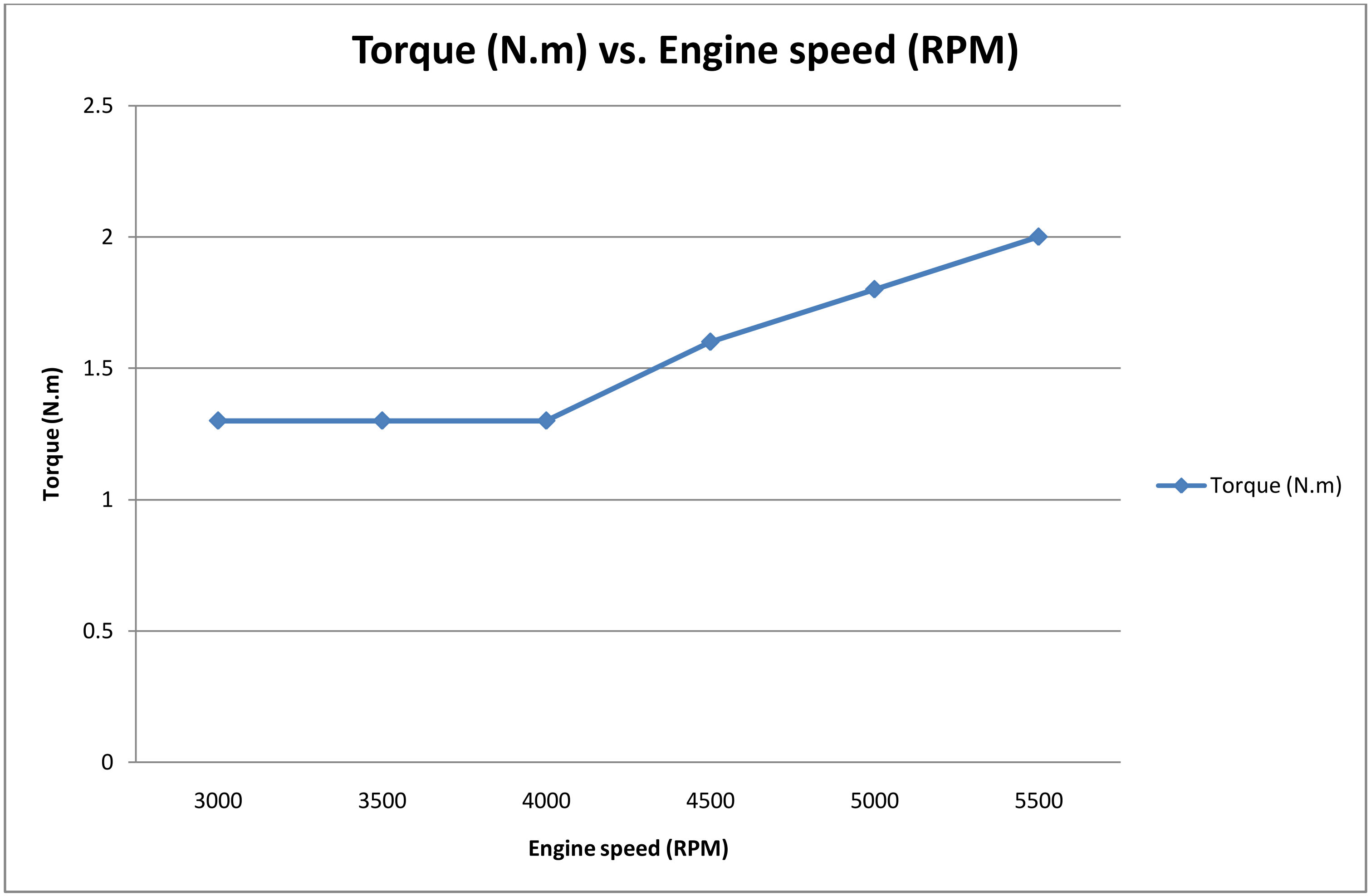


Figure 39: Graph torque versus engine speed for EFI engine

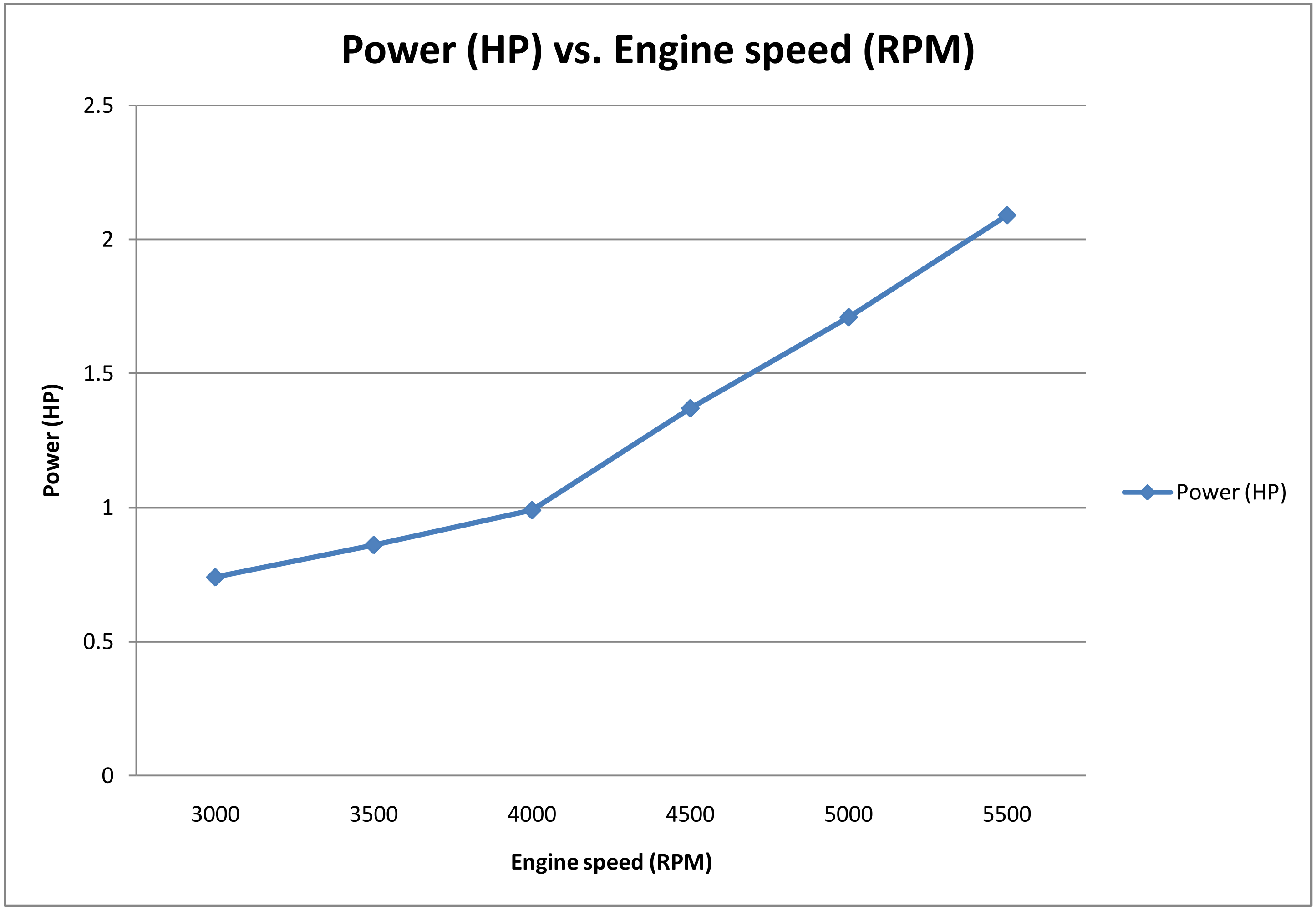


Figure 40: Graph Power vs. Engine speed for EFI engine

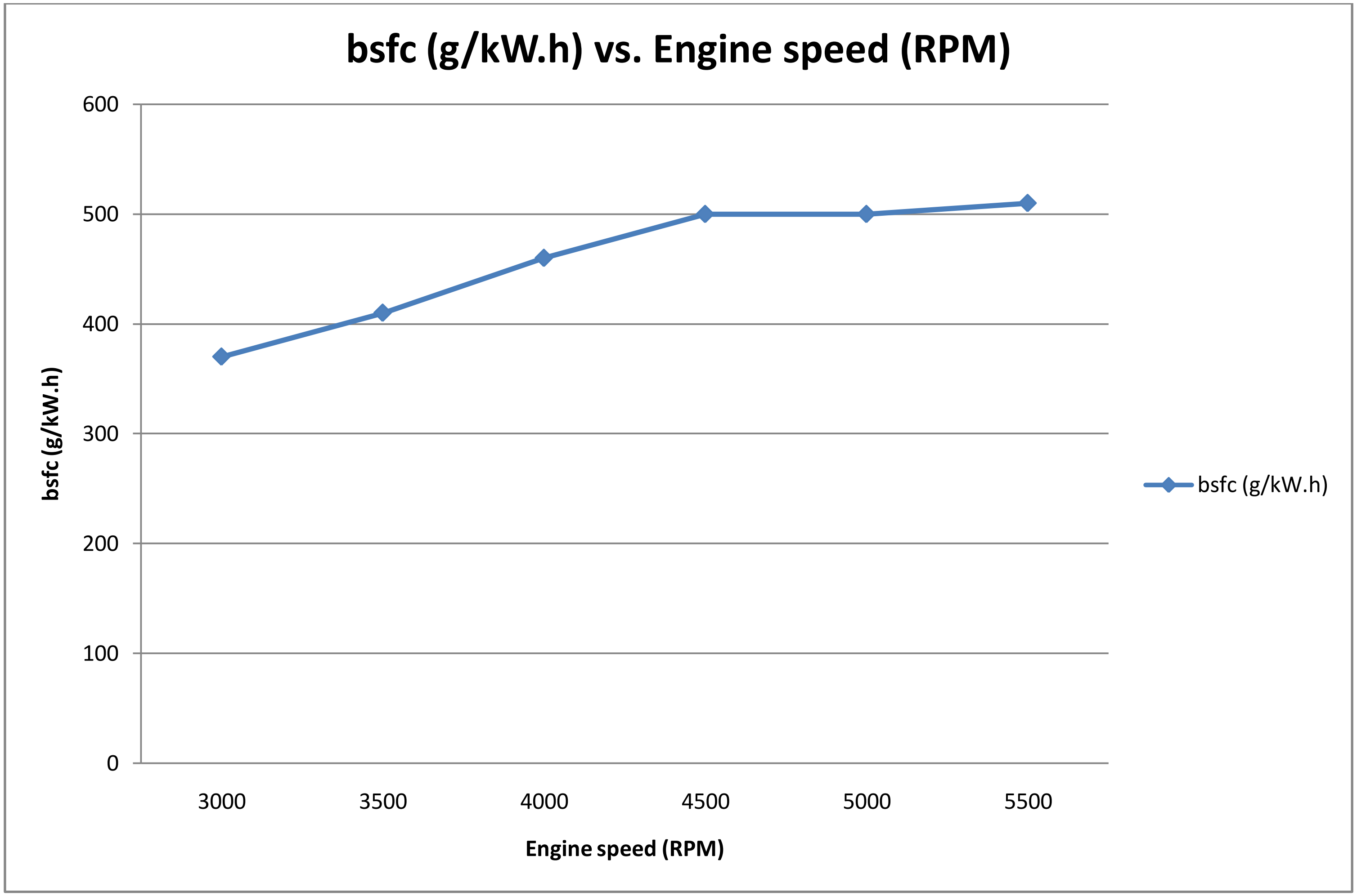


Figure 41: Graph bsfc versus engine speed for EFI engine

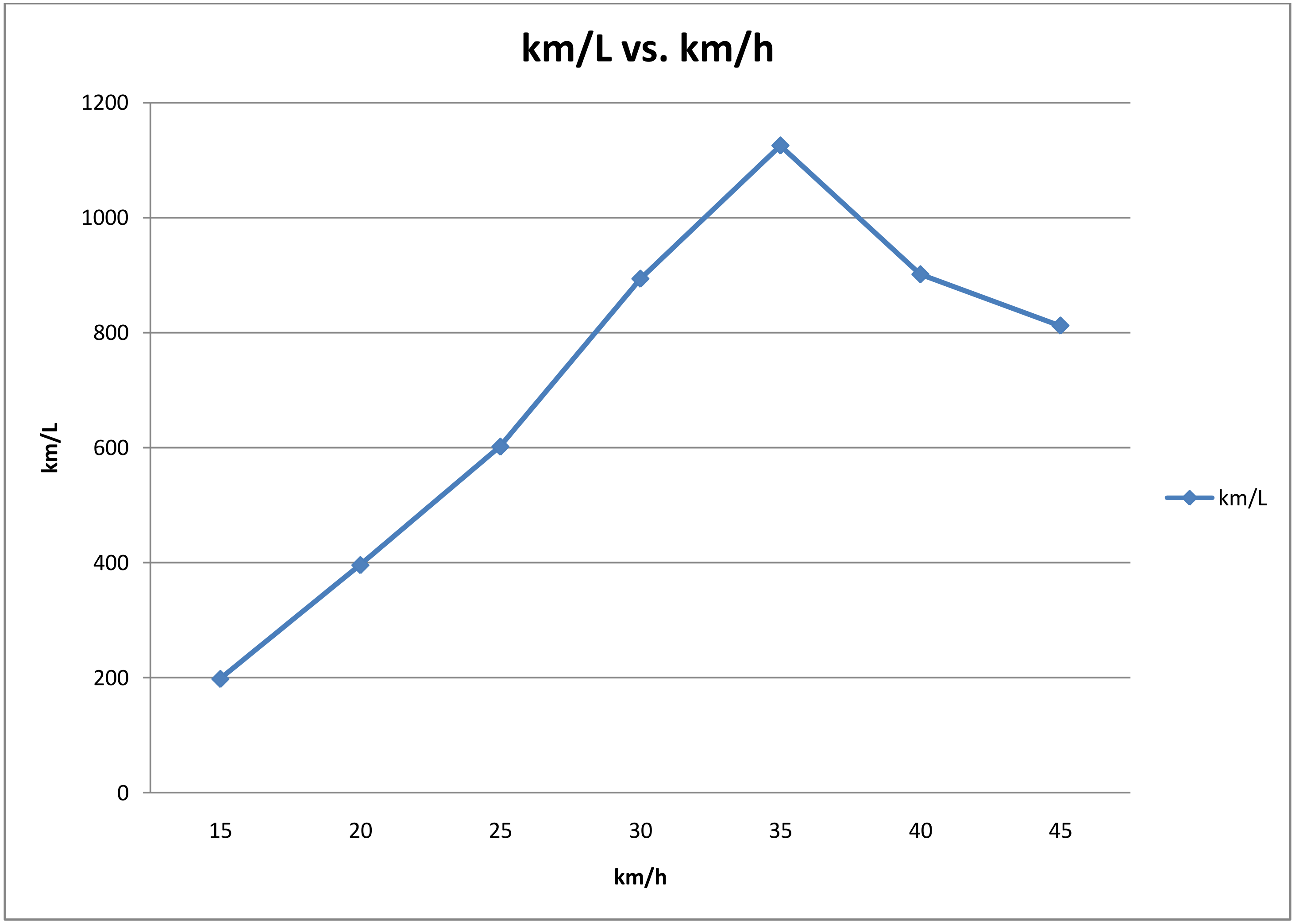


Figure 42: Graph km/L versus km/h for EFI engine