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The Effect of Intake Air Temperature on Engine Performance and Fuel Consumption of Passenger Car

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Abstract: An internal combustion engine (ICE) is a combustion process that occur inside the combustion chamber of the engine. There are 3 elements required for the internal combustion engine (ICE) which are air, fuel and ignition. These 3 elements determined the performance of a vehicle based on torque and power produced by the engine. In this research, it presents the study of the effect of air intake temperature on engine performance and fuel consumption of a passenger car. This research has been conducted with laboratory setup to analyse the fuel consumption and engine performance of the test vehicle when the air intake temperature increases. The temperature of air intake has been controlled by using heating system. The engine performance and fuel consumption have been measured using Mustang Chassis Dynamometer and On-Board Diagnostic 2 (OBD II). The test is conducted using Perodua Myvi 1.3 L with different air intake temperature which are 35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C and 70 °C. The fuel consumption and engine performance produced by the engine of the test vehicle was studied. Generally, fuel consumption decreases when the air intake temperature increases at both idle and running condition. This is because the oxygen availability inside the hot air is lower than cold air. Thus, it required small amount of fuel for combustion. This resulted in lower amount of torque and power produced by the engine when the temperature of air intake increases. The overall result shows that the engine performance is better at low air intake temperature compared high air intake temperature. The result of the experiment that was conducted become a useful source of references for those who wish to continue study on the related subject.

Keywords: Air Intake Temperature, Fuel Consumption, Engine Performance

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1. Introduction

A car or automobile is the product of the assembled components consists of engine, transmission, chassis, suspensions and tires to perform various tasks such as transportation mainly to transport people and goods. A car is powered by the engine that undergoes internal combustion inside the combustion chamber. There are 2 types of engine which are compression ignition (CI) diesel engine and spark ignition (SI) gasoline engine. Most of these engines are four-stroke engines, which means that four piston strokes are required to complete the process. The cycle consists of four distinct processes which are intake, compression, combustion and power stroke, and exhaust [1]. Both of the engines have a different range of air fuel ratio (AFR) that need to consider to ensure that the engine works perfectly. For CI engine, it has wider range of AFR which is around 20 to over 60:1 compared to SI engine which is around 12 to18:1. In a SI engine, the gasoline is combined with air and then pumped into the cylinder during the intake cycle. After the piston compresses the fuel-air mixture, the spark ignites the mixture, allowing it to flame. The movement of the combustion gasses drives the piston through the power stroke. For a CI engine, only air is inducted into the engine and then compressed. Diesel engines then spray the fuel into the hot compressed air at a suitable, measured rate, causing it to ignite [2].

1.1 Internal Combustion Engine (ICE)

Internal combustion engines (ICE) use a combination of gasoline or diesel that acts as fuel and air which contain oxygen in an acceptable ratio to generate mechanical strength. In a four-stroke internal combustion engine, the combustion cycle happens after the fuel-air mixture has been injected into the chamber, correctly compressed, and a spark has been produced in the case of gasoline/oil fuel. Internal Combustion Engine (ICE) is today one of the most commonly used engines in the automotive industry. In an engine the transfer of heat is important and very complex [3]. The fundamental thermodynamic requirements for maximizing the efficiency of the internal combustion (IC) engine cycle are studied to improve internal combustion engine efficiency [4]. A specific thermodynamic examination has to balance a vapor cycle efficiently with that of a stationary internal combustion engine (ICE) [5].

1.2 Fuel Consumption

Fuel consumption of a car will be one of the factors that people will be considered when they want to buy a car for their daily uses. Fuel consumption is important for they to consider because it will determine the cost that they will spend when they using the car. The size of the engine obviously the main factor that will affect the fuel consumption. But there are some factors that will affect the fuel consumption when the comparison is between the same type of engine of the car. The shape of the vehicle and it styling become one of the reasons that affect the fuel consumption. This is because, the aerodynamic of the car that are responsible to help the car to cut through the car. The big truck with boxy shape such as SUV and trucks have bad aerodynamic that accumulate more air resistance in front of them, raise drag, decrease performance and demand more power and thus more fuel [6]. The car driving style also become one of the factors that will influence the fuel consumption of a car. This is because, the high speed and quick acceleration need the engine to work harder to fulfil the driver need. Thus, it will reduce the fuel efficiency of the car up to 33.00 %. Then, air conditioning is a cooling system of a car is one of other factors that could affect the fuel consumption of a car. Turning on the air conditioning while driving will increase the load to engine. Therefore, it will cause more fuel to operate it.

1.3 Influences of Air Temperature on Fuel Consumption

Recent reports indicate significant variations in fuel consumption and depending on the intake air temperature. It is well known that the characteristics of combustion rely strongly on the supply of oxygen and the properties of the fuel. The excess of oxygen resulted in very lean mixture which led to unstable combustion and misfire [7]. In addition, lean mixture appears to encourage a longer delay in ignition, and a slower rate of burning resulted in longer time of combustion. This condition causes longer heat transfer time from combustion to the end gas which contributes to the phenomenon of knocking. If the engine works with a shortage of oxygen, indeed, resulting in a rich mixture resulting in higher unburned gaseous fuel leading to shorter combustion delays and quicker burning speeds [7]. It is also important to ensure that the charged air that reached the combustion chamber was sufficient of oxygen to allow complete combustion. Past research has also demonstrated that the air intake temperature plays a major role in rising the performance of combustion, stability and decreased exhaust emissions [8].

2. Methodology

Based on the literature reviews, the objective and the scope, experimental parameters were set. The test method that can be used to assess the effect of air intake temperature on engine performance and fuel consumption is followed. This study is conducted by using On-Board Diagnostic 2 (OBD II) and Mustang Dynamometer. The data collected and tabulated from the result based on the experiment.

2.1 Test Equipment

The experiment to identify the effect of air intake temperature on engine performance and fuel consumption was conducted by using Mustang Dynamometer and On-Board Diagnostic 2 (OBD II) to measure the amount of fuel usage and torque and power produced by the engine of the test vehicle which is Perodua Myvi 1.3 L.

2.1.1 Test Vehicle

The test vehicle for this experiment is run by spark ignition (SI) engine fueled with gasoline. This car has four piston movements over two engine revolution for each cycle which consist of 4 strokes. The test vehicle is Perodua Myvi, a subcompact car or supermini B-segment manufactured by Malaysian manufacturer Perodua since 2005.

Figure 1: Perodua Myvi 1.3 L (2005)

Figure 1 shows the test vehicle for this experiment which is Perodua Myvi. Table below shows the specifications of the test vehicle.

Table 1: Test Vehicle Specifications

Specifications	Descriptions
Wheelbase/length/width/height (mm)	2440/3720/1665/1550
Kerb Wright (kg)	930
Engine Type	Natural Aspirated Petrol
Cylinder	4 in-line
Capacity	1.3L (1298cc)
Fuel Tank Capacity (L)	40
Maximum Power Output	86hp/64kW at 6000 rpm
Maximum Torque	116Nm at 3200
Transmission	5 Speed Manual Transmission

2.1.2 Mustang Chassis Dynamometer

The Mustang Chassis Dynamometer is a sturdy instrument designed to add load to the test vehicle. The Mustang Chassis Dynamometer is a consolidated assembly of electrical/electronic, mechanical and electromechanical sub-systems that work together to provide the ability to replicate real road conditions while the vehicle is being tested in the test center's secure and confined space.

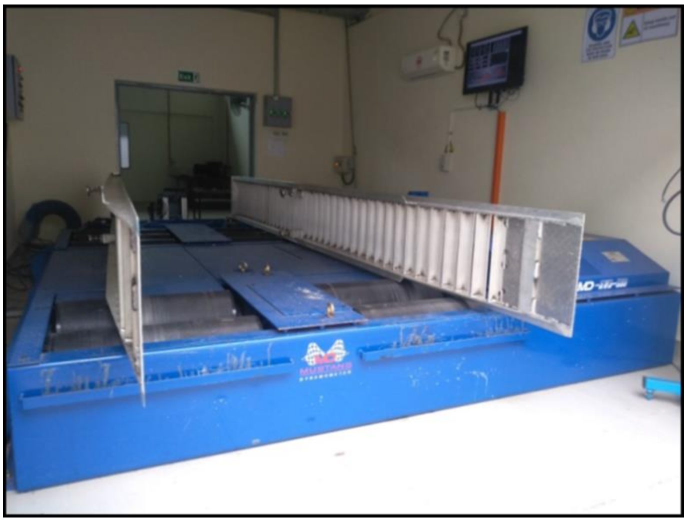

Figure 2: Mustang Chassis Dynamometer

In addition, the Mustang Chassis Dynamometer shown in Figure 2 provides the performance details of the vehicle during the test, which will also allow the user to mount test instruments and diagnostic equipment on the engine of the test vehicle to track the performance of the engine.

In the fields of performance engineering, fault diagnosis, pollution testing and test engineering around the world, the Chassis Dynamometer has become a valuable asset. A large range of vehicle tests can be performed as follows by the Chassis Dynamometer:

- Vehicle Heating and Cooling Systems.
- Engine Performance and Evaluation.
- Drive Train Component Evaluation.
- Transmission Components.
- Tire Testing.
- Fuel Efficiency.
- Failure Analysis.
- Auxiliary Components.

2.1.3 On-Board Diagnostic 2 (OBD II)

Inside an automobile, On-Board Diagnostics is a computer device that monitors and controls the performance of a car. The computer system gathers information from the sensor network inside the vehicle that can then be used by the system to control car systems or to alert the user to problems. To collect vehicle data and diagnose the issue, a technician can then simply plug in the OBD device.

The basic OBD system consists of a central system, a sensor network, a point of connection and indicators, providing a complete system of monitoring with standardized access and readability. The OBD system consists of the following components:

- Electric Control Unit (ECU).
- Sensors.
- Diagnostic Trouble Code (DTC).
- Malfunction Indicator Light (MIL).
- Diagnostic Link Connector (DLC).

2.2 Test Procedures

An experimental procedure is required for this experiment to be followed by the conductor in order to create a consistent workflow while conducting this experiment and achieve more accurate data. There are 2 experimental procedures. First experiment required heating system and OBD II while measuring fuel consumption of the test vehicle at idle condition. The second experiment required heating system, OBD II and Mustang Chassis Dynamometer in order to measure the fuel consumption and torque produced by the test vehicle.

2.2.1 Idle Condition

This experiment is conducted in order to measure the fuel consumption of the test vehicle at idle condition using OBD II. The temperature of air intake temperature is controlled by the heating system. The procedures for the experiment were conducted as follows:

i. The OBD II is connected at the steering control socket under the steering of the test vehicle.
ii. Start the test vehicle engine and wait until the engine coolant of the vehicle reaches it optimum temperature around 90 °C to 100 °C.
iii. Connect the OBD II with android tab which has OBD II software provided by the university.
iv. Connect the heating system to the power supply and turn it on.
v. Set the temperature of the air intake temperature at 35 °C using the heating system located at the air intake filter box.
vi. Wait until the air intake temperature reaches 35 °C before collecting the data from the android tab.
vii. The data then will be sent to the conductor via email.
viii. Repeat steps v until vii with different temperatures which are 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C and 70 °C.
ix. Steps from v until viii will be repeated 3 times in order to get the average of the result to make sure the result is accurate.

2.2.2 Running Condition

This experiment is conducted with the test vehicle is on the dynamometer in order to identify the effect of the air intake temperature on engine performance by measuring the torque produces by the engine and the fuel consumption while the test vehicle is moving. The air intake temperature will be controlled by heating system. The procedures for the experiment were conducted as follows:

i. Turn on the isolators to power up the dyne panel and computer system. Launch PowerDynePC software.

ii. Form the menu bar of the software shown in Figure 3, click on the 'lift' menu and select the 'up' option to raise the platform and restrain the roller.

Figure 3: PowerDynePC's software homepage

iii. Drive the test vehicle onto the dynamometer and ensure the drive wheels are appropriately placed in between the rollers.

iv. Again, from the software select the 'lift' menu and click on the 'down' option to release the restrain platform.

v. Assemble the four sets of restraining belt. Engage two of the belts at the front side of the test vehicle (cross with each other) and another two at the rear side of the vehicle (can be crossed or parallel) as in Figure 4.

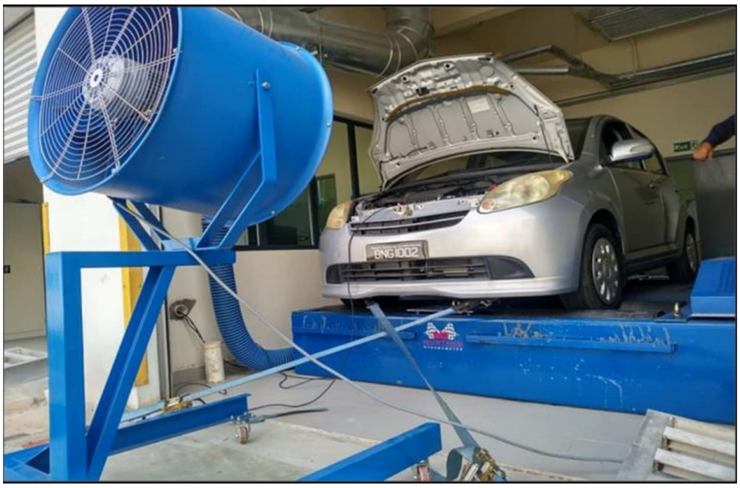

Figure 4: Test Vehicle Is Being Engage with The Belts on Dynamometer

vi. Turn on the heating system and set the temperature of the air intake temperature at 35 °C and connect the OBD II with Android tab.

vii. Set the PowerDynePC software homepage to shows the produced torque and power by the test vehicle.

viii. Drive the test vehicle in Gear 4 with engine speed at 2000 rpm and maintain the engine speed of the test vehicle at 2000 rpm.
ix. Read and collect the data of torque and power produced by the test vehicle that shows on the PowerDynePC homepage and the fuel flow rate from the Android tab.
x. Send the data from the OBD II software via email and collect the data shows from the dynamometer manually.
xi. Step vi until x are repeated with Gear 5 with engine speed at 2000 rpm and 2500 rpm.
xii. Step vi until xi are repeated with different temperature which are 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C and 70 °C.
xiii. Steps from vi until xiii will be repeated 3 times in order to get the average of the result to make sure the result is accurate.

For additional test, Power Curve test is conducted with lowest and highest temperature which are 35 °C and 70 °C. This test was conducted to identify the torque and power produce at the lowest and highest temperature. The procedures for the experiment were conducted as follows:

i. On the PowerDynePC Software homepage, select 'test' button located on the top left.
ii. Find performance and select power curve.
iii. Set the starting test engine speed at 2000 rpm and the ending test engine speed at 4500 rpm.
iv. Set the temperature of air intake temperature at 35 °C using heating system.
v. Drive the test vehicle on the dynamometer until it reaches gear 4 and reduces the engine speed until it goes below 2000 rpm.
vi. Once the engine speed is below 2000 rpm, press 'Start Dyno' on the PowerDynePC Software.
vii. The driver must press 100.00 % the test vehicle throttle pedal from 2000 rpm until it reaches 4500 rpm.
viii. Press 'Stop Dyno' on the PowerDynePC homepage.
ix. Step v until viii are repeated 3 times in order to get the average reading of the test.
x. Step iv until ix is repeated at different temperature which is 70 °C.
xi. Read and collect the data.

The experimental procedures were conducted in order to collect the data of fuel consumption when the test vehicle is in idle condition while when the test vehicle is moving, the fuel consumption, torque and power are collected. By the end of this experiment, the fuel consumption, torque and power produced by the test vehicle are collected.

3. Results and Discussion

All of the data collected are then tabulated and graphs were generated from the data obtained. The analyzing process become easier and able to come out with some discussions to be made based on the data obtained. In this section, all of the data collected were analyze and discussed.

3.1 Fuel Consumption at Idle Condition

Idling refers to operating the engine of a vehicle while the vehicle is not in motion. This usually happens when drivers are stopped at a red light, waiting outside a business or residence while parking, or otherwise stationary with the motor running. The engine runs without any loads while idling, except the engine accessories.

Figure below shows the fuel consumption of the test vehicle at different air intake temperature while the vehicle is at idle condition. The air intake temperature was set at 35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C and 70 °C.

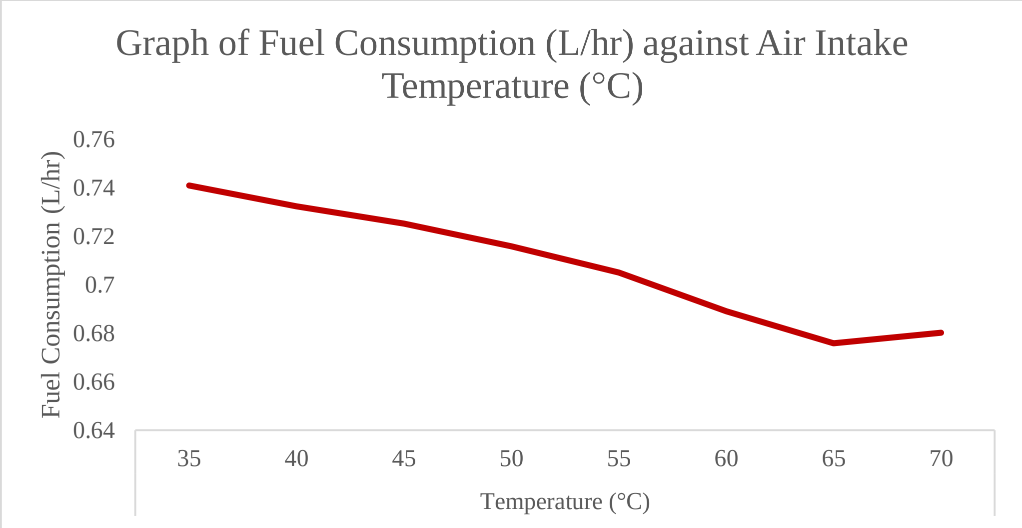

Figure 5: Graph of Fuel Consumption (L/hr) against Air Intake Temperature (°C) at Idle Condition

Based on the graph, the fuel consumption is inversely proportional with the air intake temperature. The fuel consumption decreases as the air intake temperature increase. The fuel consumption decreases when the air intake temperature increases because of the air density. When the temperature increase, the density of air become less dense. Thus, the amount of oxygen in the air decrease. This makes the amount of fuel required for combustion inside the combustion chamber is decrease. The amount of fuel decrease with the amount of oxygen because of air fuel ratio (AFR).

There are bad effects of low fuel consumption when the air intake temperature increases when the vehicle is at idle condition. It may result in an unstable combustion where partial burn and misfire may take place. Misfire in combustion makes loss of power produced by the engine and may lead to vibration which will damage the engine components in the long run. Other than that, incomplete combustion also may take place and might cause excessive carbon build up at the intake and exhaust valve at the top of the cylinder. The emissions of carbon monoxide (CO) also are expected to increase with the increase of air intake temperature. The possible reason is due to lower oxygen availability at higher temperature resulted in incomplete fuel mixing process and incomplete combustion inside the combustion chamber.

3.2 Fuel Consumption and Engine Performance at Running Condition

This section discussed about the fuel consumption, torque and power produced by the test vehicle while the vehicle was running at 3 conditions which were using gear 4 at 2000 rpm, gear 5 at 2000 rpm and gear 5 at 2500 rpm. All of these 3 conditions were selected because it is the often used by the driver while driving the vehicle on the road.

Figure 6 shows a graph of fuel consumption against air intake temperature when the vehicle is at running condition using gear 4 at 2000 rpm, gear 5 at 2000 rpm and gear 5 at 2500 rpm. The graph is inversely proportional. The fuel consumption reduces when the temperature increases at every conditions. This is because the high temperature will reduce the density of the air. Thus, the amount of oxygen available inside the air will reduce. In order to follow the air fuel ratio of the SI engine, the amount of fuel also will reduce due to less amount of oxygen in the air.

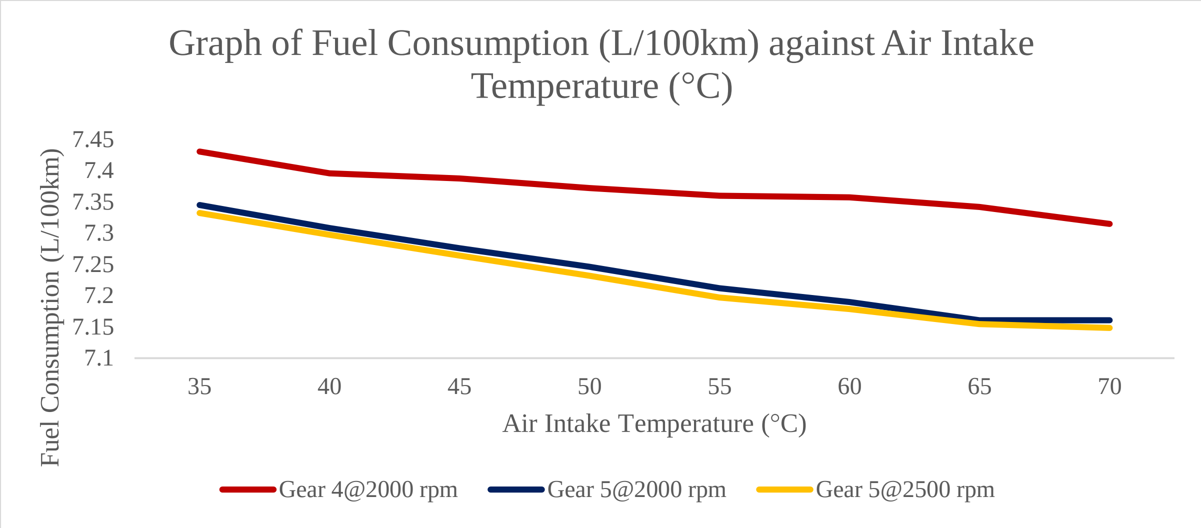

Figure 6: Graph of Fuel Consumption (L/100km) against Air Intake Temperature (°C)

Figure 7 shows the graph of torque against air intake temperature of the test vehicle when the vehicle is running using gear 4 at 2000 rpm, gear 5 at 2000 rpm and gear 5 at 2500 rpm. At all conditions, it show that the torque is decrease when the air intake increase. Torque decreases when the air intake temperature increases because the oxygen inside hot air is less than the oxygen inside cold air due to the density of air is decreases when the temperature of air increase. The less amount of oxygen inside the required less fuel for the combustion. Thus, it produces smaller force from the combustion inside the combustion chamber of the engine to push the piston to move from TDC to BDC during power stroke.

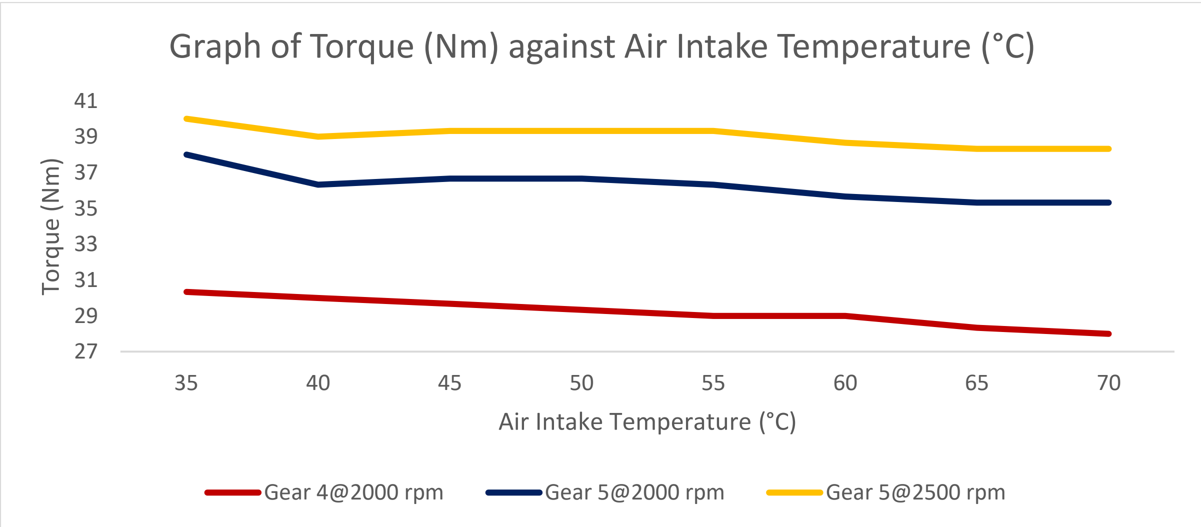

Figure 7: Graph of Torque (Nm) against Air Intake Temperature (°C)

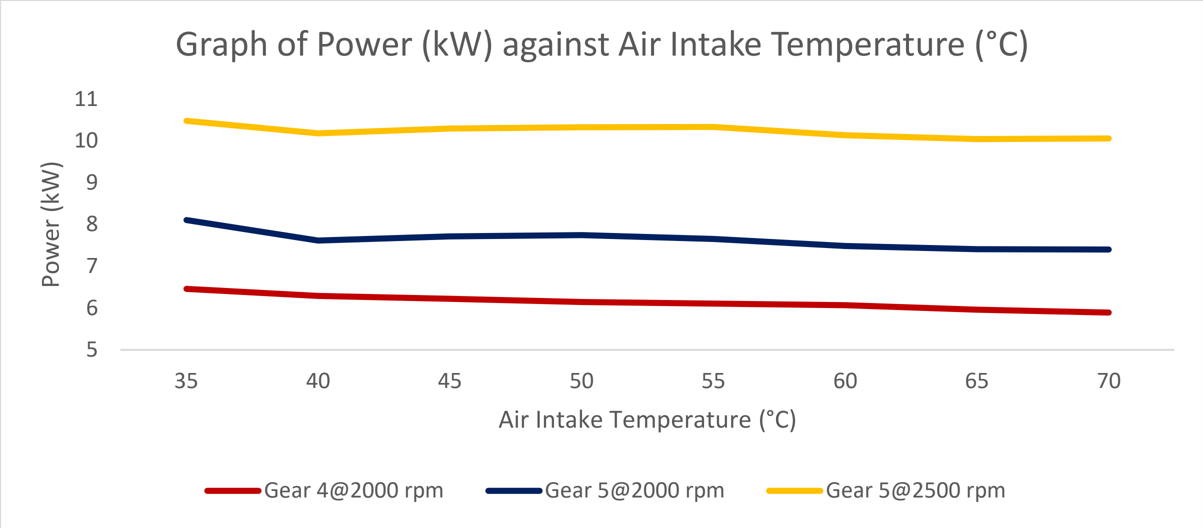

Figure 8: Graph of Power (kW) against Air Intake Temperature (°C)

Figure 8 shows a graph of power against air intake temperature of the test vehicle when the vehicle is running using gear 4 at 2000 rpm, gear 5 at 2000 rpm and gear 5 at 2500 rpm. At all conditions, it show that the power is decrease when the air intake temperature increase. Torque decreases when the air intake temperature increases because the oxygen inside hot air is less than the oxygen inside cold air due to the density of air is decreases when the temperature of air increase. The less amount of oxygen inside the required less fuel for the combustion. Thus, it produces smaller force from the combustion inside the combustion chamber of the engine to push the piston to move from TDC to BDC during power stroke. The power also decreases when the temperature increases because power was related with torque. When the torque produced decreases, the power also decreases.

3.3 Power Curve

Power curve may refer to the power band of an internal combustion engine, the range of speeds in which it operates efficiently. This experiment was carried out by using Mustang Chassis Dynamometer to measure the amount of torque and power produced by the engine of the test vehicle when driving using gear 4 at 2000 rpm until 4500 rpm at 2 different of air intake temperature which are 35 °C and 70 °C.

Figure 9 shows graph of torque against engine speed at 35 °C and 70 °C of air intake temperature from 2000 rpm to 4500 rpm. The test was run 3 times for each temperature and the data collected for every run were used to find the average to get the most accurate data. Based on the figure, before the engine speed reaches 2500 rpm, the torque produced by the engine at 70 °C was higher that the torque produced at 35 °C. This may cause by the different driving style shows by the driver while conducting this experiment. After engine speed reaches 2500 rpm, the torque produced by the engine at 35 °C was higher compared to torque at 70 °C.

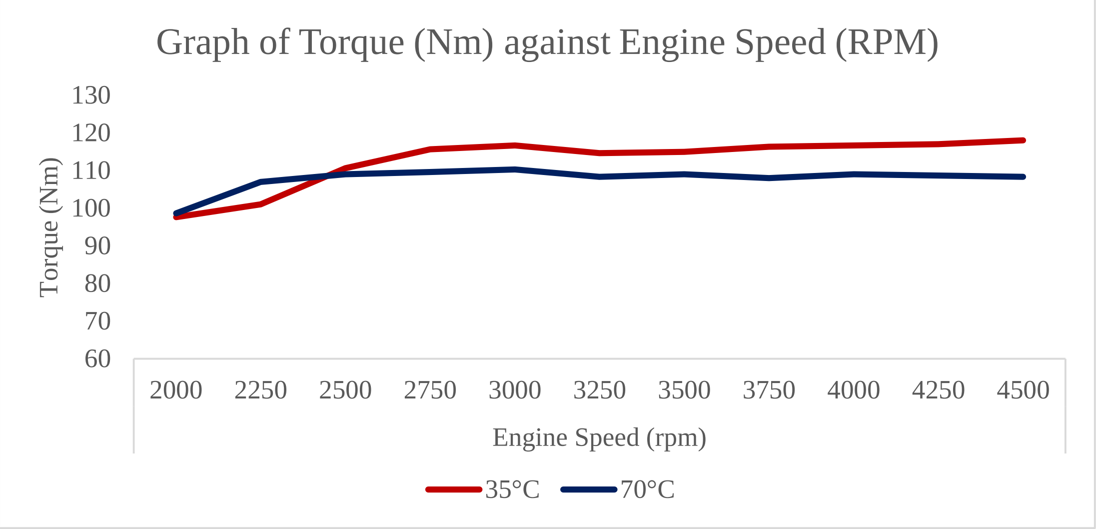

Figure 9: Graph of Torque (Nm) against Engine Speed (rpm) at 35°C and 70°C of Air Intake Temperature

Figure 10 shows graph of power against engine speed at 35 °C and 70 °C of air intake temperature from 2000 rpm to 4500 rpm. The test was run 3 times for each temperature and the data collected for every run were used to find the average to get the most accurate data. Based on the figure, before the engine speed reaches 2500 rpm, the power produced by the engine at 70 °C was higher that the power produced at 35 °C. This may cause by some errors on machine while conducting this experiment. After engine speed reaches 2500 rpm, the power produced by the engine at 35 °C was higher compared to power at 70 °C.

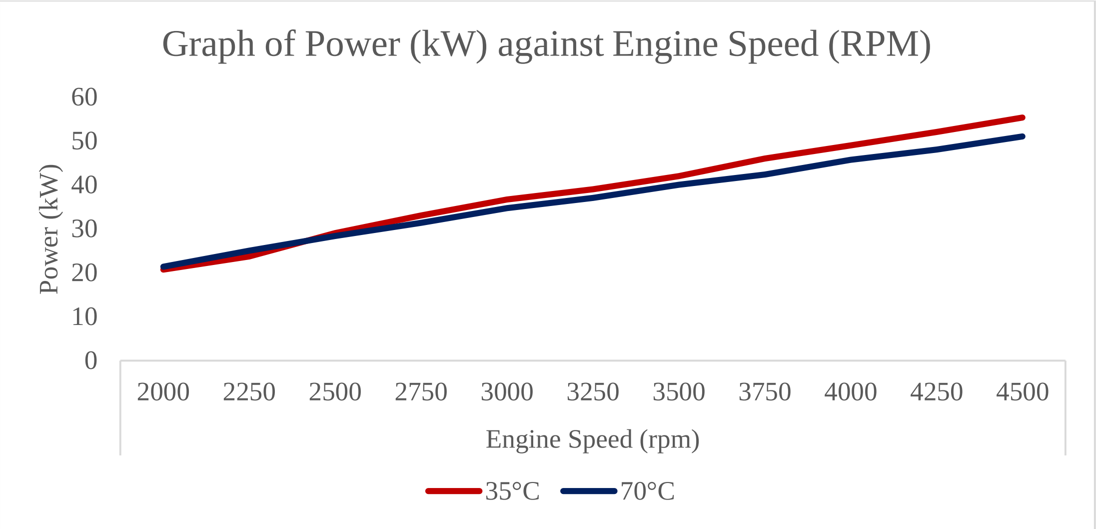

Figure 10: Graph of Power (kW) against Engine Speed (rpm) at 35 °C and 70 °C of Air Intake Temperature

From both Figure 9 and Figure 10 show that at lower air intake temperature, the torque produced by the engine of the test vehicle was greater than the torque produced at the higher air intake temperature. Same goes with power, when the air intake temperature was low, the power produced was higher compared to the power produced when the air intake temperature was high.

4. Conclusion

The objectives of the experiment were achieved. The experiment was conducted by using a test vehicle which was Perodua Myvi 1.3 L with spark ignition (SI) engine. Different in air intake temperature has proven that it affected the fuel consumption and the engine performance of the vehicle. The test vehicle was tested with 2 types of experiments with different air intake temperature. The air intake was set with various temperature which were 35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C and 70 °C to detect the effect of the increment in temperature towards fuel consumption and engine performance.

The increment in air intake temperature reduced the fuel consumption of the test vehicle. This was because, when the temperature increase, the density of air will reduce. Thus, it will reduce the oxygen availability in the air and the amount of fuel required for combustion will decrease due to air fuel ratio. When the amount of oxygen and fuel are low, the combustion produced will be weaker. This will be resulted into lower torque and power produced by the engine. Other than that, low fuel consumption when the vehicle is at idle condition may cause misfire inside the combustion and cause vibration to the engine that may damages the engine component.

As a conclusion, when the air intake temperature increases, the fuel consumption will decrease. Thus, the engine performance which depends on torque and power also decreases. It is confirmed that the objectives of this study are achieved because the effect of air intake temperature when the test vehicle is at idle condition was identified and the amount of fuel consumption, torque and power produced by the engine at different air intake temperature were studied.

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