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Effects of Air Intake Pressure to the Fuel Economy and Exhaust Emissions on a Small SI Engine

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Abstract

This study discusses on the fuel economy and exhaust emissions at variations of air intake pressure. The air intake pressure is influenced by the degree of opening throttle plate and venturi effect which draw the fuel to the combustion chamber in carbureted engine. The experimental work is conducted at variations of engine speed and load using a single cylinder four stroke SI engine attached with 5kW dynamometer. Gas analyzer was used to measure exhaust emissions compositions and to identify the quality of combustion. The results show that the standard air intake system resulted in rich combustion which led to the incomplete combustion due to less availability of air. By eliminating the air filter, the air flow restriction through the air intake system was reduced. Hence, better combustion and less unburned components are achieved because of higher air availability. A higher air intake pressure is required to increase air density in allowing for better combustion within a limited time to improve fuel economy, power output and exhaust emissions. Complete combustion also lead to the reduction of unburned components such as carbon (C), hydrogen (H_2), carbon monoxide (CO) and hydroxide (OH) that resulted in less hazardous emissions.

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Keywords: Air intake pressure; air filter; fuel consumption; exhaust emissions

Nomenclature

N	Number of Moles
$\dot{V}_K$	Fuel Consumption (l/hour)
t	time
S.G.	Specific Gravity
vol %	Volume Percentage
ppm	Parts per Million

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1. Introduction

The engine performance can be enhanced by introducing leaner air fuel mixture which caused by higher air intake pressure to improve the combustion process. Reducing the restriction of air filter element is the simplest method to improve the flow of air intake. Air filter reduces the pollutant particles in the air intake into a safe level for engine to operate. However, the air filter element restricts the flow of air intake and leads to the pressure difference between atmospheric pressure and pressure at the outlet of the intake system. In this project, the air intake pressure was observed at the downstream of the air filter. This helps in identifying the best characteristics of the air intake for improving engine performance with a better fuel economy and lower exhaust emissions. The testing was conducted in a control chamber which has clean air to avoid the polluted air damaging the internal engine components. In a complete combustion, the hydrocarbon fuel reacts completely with the dry atmospheric air as explained on Equation 1. In incomplete combustion generally, it will has such unburned components of C, H_2, CO, NO_x, CH_4 and OH [1].

$$C_N H_{2N+2} + (3N + 1)(O_2 + 3.76N_2) \rightarrow NCO_2 + (N + 1)H_2O + 3.76(3N + 1)N_2 \quad (1)$$

An ideal tube length of the air intake system, *L (m)* is inversely proportional to the engine speed, *n (rpm)* with respective to the constant acoustic speed, *a (m/s)* as explained in Equation 2 [2]. The theory of ideal tube length is applied on the Variable Intake Manifold (VIM) system. The system uses a long intake runner at low engine speed as it makes low velocity of air intake which optimizes the air-to-fuel mixing coefficient. The short intake runner is switched at higher engine speed to increase the flow of air intake at higher engine speed so that the combustion efficiency is increased within a short period of the intake stroke. Ceviz and Akin 2010 state that the longer intake plenum length is averagely suitable for 1000 rpm to 3000 rpm of engine speed and the shorter intake plenum length is averagely suitable for engine speed higher than 4000 rpm [3].

$$L \approx (10 \times a)/n \quad (2)$$

A clogged air filter restricts the air flow, increases the fuel consumption and reduces air-to-fuel mixing coefficient. Despite a clogged air filter in injection engine, a lean air-to-fuel mixture is maintained thanks to closed-loop algorithm in controlling the flow rate of injected fuel [4]. Hence, the condition of air filter does not affect the air-to-fuel mixture of the fuel injected engine. On the other hand, a traditional carbureted engine does not have the closed-loop algorithm fuel control. Insufficient air-to-fuel mixture is supplied into the combustion chamber of the carbureted engine when the air filter is clogged. In order to study the fuel consumption characteristics due to the clogged filter effect, a carbureted engine that was taken out from Subaru EX17 was used. In this project, an air filter was installed into the engine to demonstrate the clog effect on the engine performance. Thereafter, the air filter was taken out to demonstrate on clogging effect and the data was measured so that results can be compared.

Based on Rizalman Mamat, et al., higher pressure drop in air intake system which occurs during part load and low load reduces the engine efficiency and increase the engine brake specific fuel consumption, BSFC. The NO_x emission is majorly influenced by the air fuel ratio, AFR compared to the ignition delay especially during part load. The engine combustion and emissions behaviours are affected by the magnitude of inlet manifold pressure drop on both usages of ultra low sulphure diesel, ULSD and rapeseed methyl ester, RME [5]. Reduction on both carbon monoxide, CO and hydrocarbon, HC with constant on both oxygen, O_2 and carbon dioxide, CO_2 are caused by the reduction of engine altitude, increment in air intake pipe diameter, higher atmospheric pressure and higher engine speed [6]. The reduction in HC emission is due to improved combustion process because of larger air intake pipe diameter at higher engine speed. Meanwhile, the CO emission is affected by the volume of injected fuel which burnt based on the amount of oxygen during the combustion process.

2. Experiment Setup and Procedure

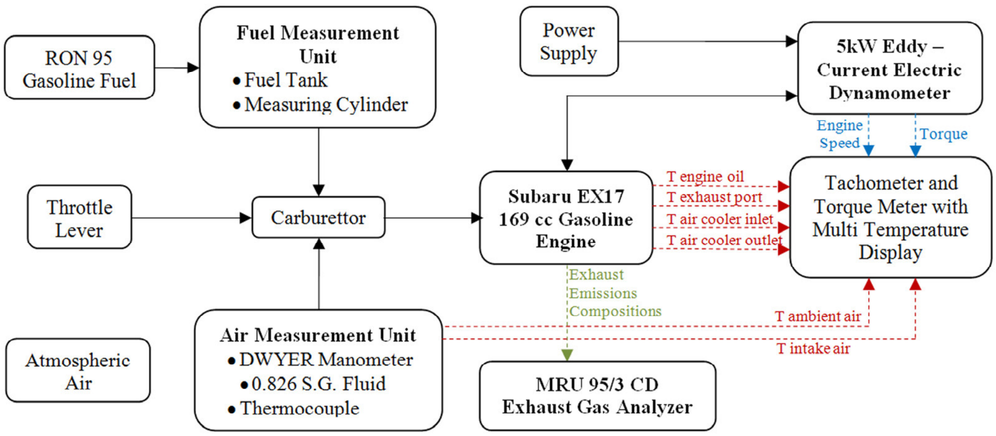

Fig. 1. Overall experiment instruments layout

Based on two experiment variables which are the air intake system with air filter and the air intake system without air filter, the engine speed is increased along the constant load applied to the engine in order to obtain the effects of air intake pressure throughout engine operating conditions. The overall experiment instruments layout is explained in Figure 1. On each single run, multiple data such as temperatures at 6 points on engine and air measurement unit, atmospheric air temperature and humidity, engine speed and load, voltage and current supplied to dynamometer, fuel consumption and exhaust emissions compositions are recorded.

Table 1. Subaru Robin EX17 Engine Specifications

Type	Air-Cooled, 4-Stroke, Single Cylinder, OHC
Bore x Stroke (mm)	67 x 48
Displacement (cc)	169
Maximum Output (kW/rpm)	4.2 / 4000
Maximum Torque (Nm/rpm)	11.3 / 2500

$$\dot{V}_K = \left(\frac{V_{fuel}}{1000}\right) \div \left[\left(\frac{t_{min}}{60}\right) + \left(\frac{t_{sec}}{3600}\right)\right] \qquad \left(\frac{l}{hour}\right) \tag{3}$$

In measuring the fuel consumption in liter per hour (l/hour) unit, the volume of fuel consumed is divided with a period of time as explained in Equation 3. At least 40 seconds of time period from the time the probe sense the exhaust gases is needed to obtain the exhaust emissions compositions data for the gas analyzer to produce the consistence data. According to its manual, O_2 sensor needs approximately 20 seconds, 30 seconds for CO sensor, 30 seconds for SO_2 sensor and 30 seconds for the NO sensor [7]. The gas analyzer probe is located at 120 cm from the exhaust port. The atmospheric pressure is ignored as it is assumed to be constant through entire experiment process to obtain the air intake gauge pressure. Air intake gauge pressure is the one being measured by using the water column height, h from manometer. The point to measure the air intake gauge pressure is 23 cm from the air filter. The spark plug with gas analyzer's probe and filter are cleaned after 5 runs in maintaining the engine efficiency and consistency of gas analyzer.

3. Results and Discussions

This analysis of data is carried out based on constant load. The approach of this data analysis is carried out in order to study the pattern of each output data behavior towards the manipulation of engine speed at constant load.

Table 2. Data Analysis Based on 1 Nm of Constant Load and Increasing Engine Speed

Variables	Condition	Engine Speed, rpm	Torque, Nm	Power, kW
Without Air Filter / With Air Filter	1	1500	1	0.157
	2	2000	1	0.209
	3	2500	1	0.262

3.1. Fuel Consumption

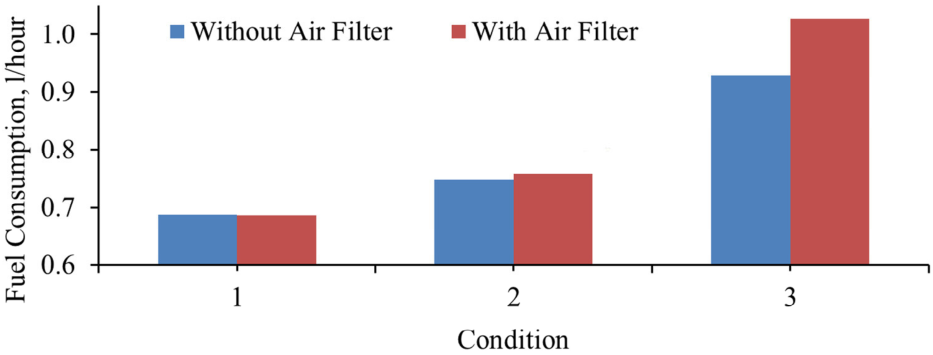

Fig. 2. Graph of Fuel Consumption at Constant Load

The fuel consumption is increasing by 49.6 % which is from 0.687 l/hour to 1.028 l/hour on the variable with air filter. But, only 35.2 % increment of fuel consumption is achieved by the variable without air filter which is from 0.687 l/hour to 0.929 l/hour. It shows that without air filter, the fuel consumption is lower compared to the variable with air filter on all three conditions.

As the load is fixed and the engine speed is increased, the air intake flow rate is increased due to larger throttle opening and more vacuum suction is created inside the engine cylinder to inhale more volume of air fuel mixture which increases the fuel consumption. Furthermore, higher engine speed has lower period of time for the engine to inhale a complete volume of air fuel mixture into the engine cylinder. The air fuel mixture is unable to flow into cylinder completely as the intake valve is already being closed. So, with the increased air intake pressure caused by the absence of air filter, the air fuel mixture is forced more aggressively to improve the cylinder filling. The fuel consumption is affected by the air fuel ratio which leaner combustion will less consuming the fuel while richer combustion will more consuming the fuel [8].

3.2. Air Intake Gauge Pressure

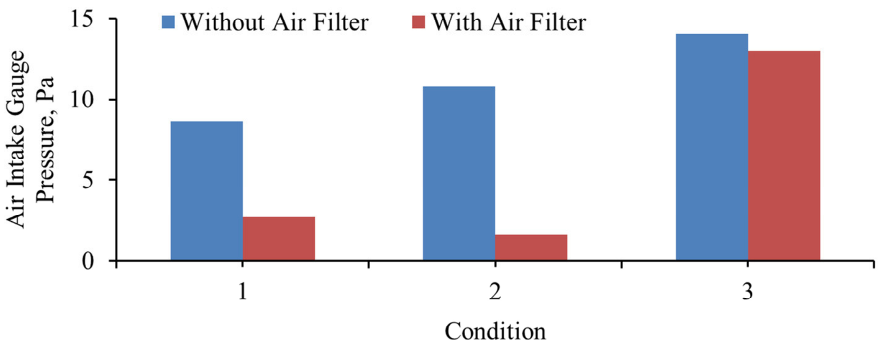

Fig. 3. Graph of Air Intake Gauge Pressure at Constant Load

The differences of air intake gauge pressure between both variables without air filter and with air filter are bigger especially on conditions 1 and 2. On the condition 1, the air intake gauge pressure for the variable with air filter is only 2.701 Pa which is about 31.2 % of the 8.642 Pa air intake gauge pressure for the variable without air filter. While for the condition 2, the air intake gauge pressure of variable with air filter is just 1.621 Pa. That is only about 15 % of the air intake gauge pressure for the variable without air filter which is 10.804 Pa. On condition 3, the air intake gauge pressure of variable with air filter is 12.965 Pa which is about 1.08 Pa less than the 14.045 Pa of air intake gauge pressure for variable without air filter.

The air intake pressure in naturally aspirated engine is mainly affected by the engine speed. Higher air intake pressure occurs on the higher engine speed. In forced induction engine, the air intake pressure is mainly forced by the compressor to maintain high air intake pressure through entire engine speed especially on high engine speed. During high engine speed, the time is limited for the air fuel mixture to enter the cylinder, but without air filter which promotes to higher air intake pressure, it helps the cylinder being filled with the sufficient amount of air fuel mixture in ensuring optimum performance on entire engine speed. Thus, it is necessary to make sure the air filter is always in clean condition.

3.3. CO_2 Emission

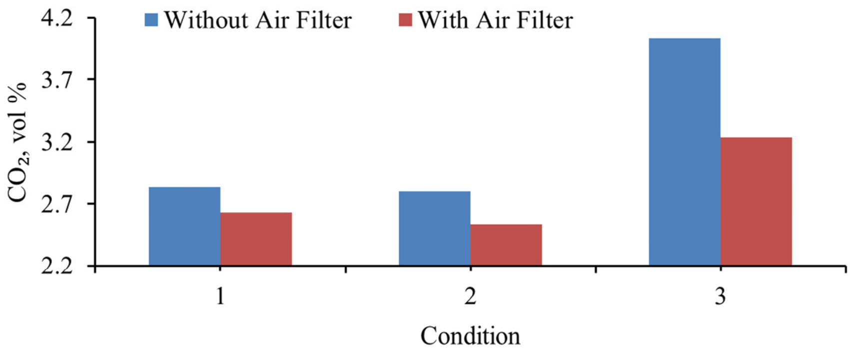

Fig. 4. Graph of CO_2 Composition at Constant Load

The most obvious difference between carbon dioxide volume percentages of both variables without air filter and with air filter is on condition 3, the carbon dioxide composition volume percentage of variable without air filter is 25 % more than the variable with air filter. While, for the conditions 1 and 2, the volume percentage of carbon dioxide composition for variable without air filter are only 7.7 % and 12 % more than the variable with air filter respectively.

The carbon dioxide volume percentage is lower on the condition with air filter and higher on the condition without air filter at all conditions. This is because as the air becomes less restricted due to unavailable air filter, leaner air fuel mixture is formed which optimizes the efficiency of combustion process. Combustion process that approaches to the complete process will produce more carbon dioxide and higher exhaust gas temperature [9-10]. In the other hand, condition with air filter is more restricting the air flow which contributes to richer air fuel mixture and lower quality of combustion process with less carbon dioxide is formed.

3.4. NO_x Emission

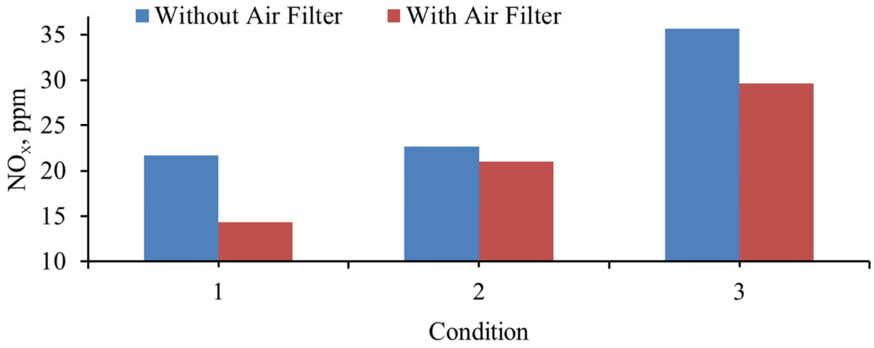

Fig. 5. Graph of NO_x Composition at Constant Load

The NO_x formation of variable without air filter is more than the NO_x formation of variable with air filter. On the condition 1, NO_x formation of without air filter is 51.7% more than the NO_x formation of variable with air filter. For both conditions 2 and 3, the formation of NO_x for variable without air filter are 8.1% and 20.2% more than the NO_x formation of variable with air filter respectively.

This NO_x composition result supports the Zeldovich mechanism theory. Based on Zeldovich mechanism, the NO_x formation is influenced by the maximum temperature and pressure of the combustion process [11]. Without air filter, the combustion process is better which leads to higher temperature and pressure formed during the process. With the higher in-cylinder temperature and pressure that is caused by better combustion, the NO_x formation is higher [12]. Thus by comparing the theory of Zeldovich mechanism with the experiment result, it is agreed that the increase in combustion pressure and temperature on the condition without air filter increases the formation of NO_x. Higher pressure drop on variable with air filter reduces the NO_x formation.

3.5. Exhaust Gas Temperature

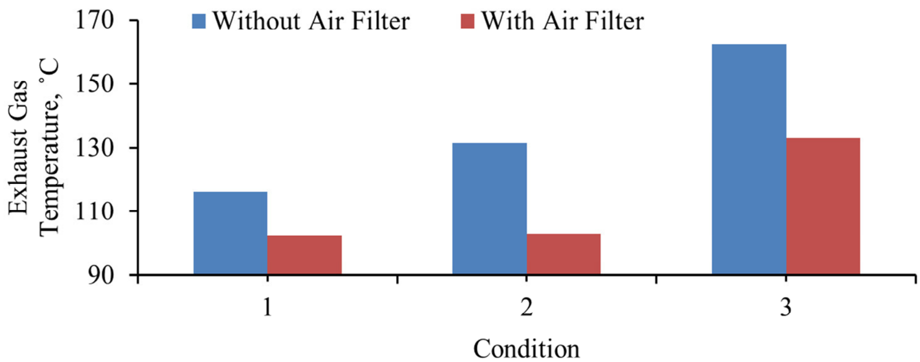

Fig. 6. Graph of Exhaust Gas Temperature at Constant Load

The exhaust gas temperature is higher on the variable without air filter compared to the variable with air filter. The exhaust gas temperature on the variable without air filter are 13.39 %, 27.45 % and 22.19 % higher compared to the exhaust gas temperature on the variable with air filter through conditions 1, 2 and 3 respectively.

As the fixed load applied, the increasing engine speed has higher number of power strokes per period of time which has more combustion process than lower engine speed and increases the exhaust gas temperature. Higher exhaust gas temperature leads to higher pressure as explained in the ideal-gas equation of state, $Pv = mRT$. According to Abdullah, Mamat et al., better combustion generates more heat during the process and it raises the exhaust gas temperature [12]. Without air filter, the combustion process is improved due to higher air intake pressure which transforming more fuel's chemical energy into heat energy that raises the exhaust gas temperature to be higher compared to variable with air filter.

4. Conclusion

The engine behaviour in engine performance, fuel consumption and exhaust emissions aspects are influenced by the magnitude of air intake pressure. It needs to form leaner air fuel mixture to extract more energy from the combustion process. The large amount of air increases the potentiality of fuel chemical elements to be burned with oxygen. As a result, the engine performance and fuel economy are increased while the unburned exhaust emissions components are reduced.

This study will encourage the vehicle users to ensure their vehicle's air filter is always in clean and good condition. Ensuring clean and good condition of air filter will maintain higher air intake pressure and absorption of polluted particles through air filter. Clogged and dirty air filter reduces the air intake pressure and thus the engine performance and fuel economy. Moreover, if the engine uses carburettor which unable to manipulate the amount of gasoline to be mixed with air based on exhaust emissions quality, the engine's fuel economy will become worst and so do the engine output and emissions.

The air filter maintenance is very crucial in order to improve vehicle fuel economy and reducing hazardous exhaust emissions. It is true in conjunction with today's issues such as the fuel price which getting more expensive and increasing human awareness towards the importance of green revolution. Improved fuel economy will help us save our expenses besides reducing our usage or dependency on depleting fossil fuel. Moreover, with the reduced hazardous emissions being released to the environment, we could prevent the earth from further devastation for our next generation.

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