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Analysis and Comparison of Engine Performance and Exhaust Emissions of Internal Combustion Engine for Three Different Fuel Efficiency Devices

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ABSTRACT

The engine performance and exhaust emissions characteristics of an internal combustion engine using three different fuel efficiency devices, namely Hiclone, Supermax and FFC are analyzed compared and discussed in this paper in order to identify the best fuel efficiency device among three. The testing was done in a 2.4L 4-cylinder Toyota Camry 2AZ-FE engine. The procedure recommended by Environmental Protection Agency (EPA) Aftermarket Retrofit Device Evaluation Program was used for engine testing. All the results obtained were when the devices were fitted and compared with results when no device was fitted with the engine. This study found that there is no significant increase/decrease of brake power, brake torque, fuel consumption and exhaust emissions for these fuel efficiency devices. Further study is recommended in order to come to an acceptable conclusion.

INTRODUCTION

Research on pollutant emissions from internal combustion engines have been intensified due to increasing claims from environmental protection organizations [1, 2, 4 and 5]. A fuel efficiency device is a device that claims to improve the fuel economy and reduce emissions from a vehicle. The design of a fuel efficiency device varies, however many are designed to fit on the carburettor or intake of an engine. There are several types of fuel efficiency devices available in the market, such as magnets, fuel catalysts, platinum injection, ignition enhancers, air bleed devices and vortex generators. Three types of fuel efficiency devices are used in this study. These are Hiclone, Supermax or Super fuel max and The Fitch Fuel Catalyst (FFC) [7]. Hiclone is a simple non-moving and maintenance-free device. It is made of stainless steel, which fits inside the air filter housing of a carburettor or in the air induction hose on electronic fuel injection (EFI), turbo, and liquid petroleum gas (LPG) or diesel engines. It creates a swirling cyclone or tornado like effect to the airflow into the intake manifold and combustion chamber of any engine. Super fuel Max/Supermax influences on gasoline, gas or diesel fuel, putting molecules in order, and therefore when molecules entering the combustion chamber area, fuel burns more efficiently. The FFC is a pre combustion fuel treatment device the purpose of which is to improve combustion [7].

Literature reports that as long there are cars, there are devices that assure improvements in performance and mileage [3]. It seems that if there is rise in fuel prices, the fuel efficiency devices proliferate and become increasingly popular. The fuel efficiency devices are advertised in various ways including the internet, car dealerships and classified advertisements in the back of magazines and all claim to boost power, reduce emissions and improve fuel consumptions [3]. In fact, most devices claim about 10-15% fuel saving, emissions reduction and performance improvement [8].

The United States (US) Environmental Protection Agency (EPA) conducts a program to evaluate aftermarket retrofit devices which claim to improve vehicles fuel economy and/or reduce fuel emissions [9]. The purpose of the program is to generate, analyse and disseminate technical data of fuel efficiency devices. Through engineering and/or statistical analysis of data from vehicle tests, the evaluation program determines the effects on fuel economy, fuel emissions, durability and drive-ability of the applicable vehicles due to the installation or use of the device.

In this paper engine technology, exhaust emissions and energy efficiency for an internal combustion engine, located in subtropical Central Queensland (Australia), are studied with a view to improving fuel economy and reduce gas emissions through the use of three fuel efficiency devices. Therefore an investigation and analysis has been performed taking into considerations of three different fuel efficiency devices; they are Hiclone, Supermax and FFC. Performance characteristics such as brake power (BP), brake torque (BT) and fuel consumption (FC), and exhaust emission for these fuel efficiency devices, are performed, compared and discussed. Engine was tested when devices were fitted with engine which was compared with the results obtained when no devices were fitted with the engine.

NOMENCLATURE

BP	[hp]	*Brake power*
BT	[N m]	*Brake torque*
CO	[-]	*Carbon Monoxide*
CO2	[-]	*Carbon Monoxide*
EFI	[-]	*Electronic Fuel Injection*
EGA	[-]	*Exhaust gas analyser*

EPA	[-]	*Environmental Protection Agency*
FC	[kg/kJ]	*Fuel Consumption*
FFC	[-]	*The Filtch Fuel Catalyst*
GHG	[-]	*Greenhouse Gases*
HC	[-]	*Hydrocarbons*
LPG	[-]	*Liquid Petroleum Gas*
NO	[-]	*Nitric oxide*
NOx	[-]	*Nitrogen oxide*
NDIR	[-]	*Non dispersive inferred sensor*
PM	[-]	*Popular magazine*

ENGINE PERFORMANCE AND EMISSIONS

The performance of an internal combustion engine could be analyzed using the brake power (BP), brake torque (BT) and fuel consumption (FC). The brake power and torque are generally assessed using an engine dynamometer, where the dynamometer is coupled directly to the flywheel of the engine (Figure 1). The fuel consumption is analyzed using an appropriate flow measuring device. Positive displacement flow meters are perhaps the most practical method to measuring fuel mass flow for this application. Positive displacement flow meters make volumetric flow measurements taking finite increments or volumes of the fluid. These types of meters come in several forms including the reciprocating/oscillating piston, oval gear, rotary vane and diaphragm.

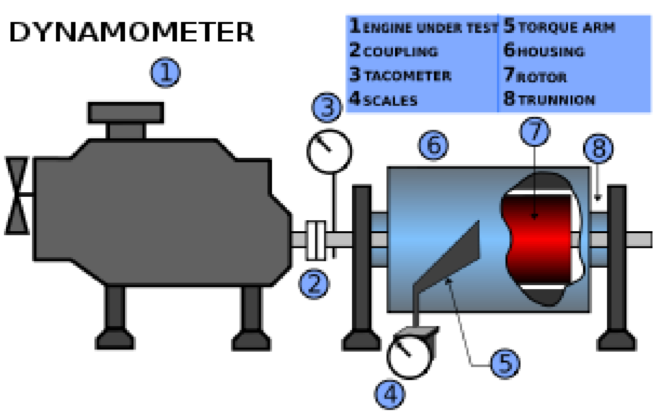

Figure 1: Engine dynamometer schematic

Internal combustion engines emit a number of greenhouse gases (GHG) and pollutants which are harmful to the environment. The five gases emitted through the exhaust include carbon dioxide, carbon monoxide, nitrogen oxides, hydrocarbons and oxygen. Carbon Monoxide (CO) is always present in the exhaust gases due to the dissociation with processes. With rich mixtures the CO concentration is further increased due to the incomplete combustion to carbon dioxide. Carbon dioxide (CO_2) is one of the five main greenhouse gases in the earth's atmosphere. CO_2 is a non regulated emission, but is frequently measured when analyzing exhaust gas emissions as it gives valuable clues on fuel consumption in dynamometer tests. Nitrogen oxide (NO_x) is typically any binary compound of oxygen and nitrogen, such as Nitric oxide (NO) and Nitrogen dioxide (NO_2). In high concentrations, NO_x is very toxic, therefore a significant contributor to air pollution and smoke. Hydrocarbons (HC) are defined as any compound consisting entirely of hydrogen and carbon. Hydrocarbons appear in the exhaust gas from a number of sources. Some of these can be directly related to unstable ignition, some to poor operation and some to crevices in the combustion chamber which are too narrow for the flame to enter.

EXPERIMENTAL SET UP AND PROCEDURE

Equipment

The test engine used in this study was a 2.4L 4-cylinder Toyota Camry 2AZ-FE engine. The engine is generally used for laboratory experiments and demonstrations only, therefore was in very good condition. The characteristic curve, shown in Figure 2, indicates that the maximum torque is 218 N m at 4000 rpm and maximum power is 117 kW at 5700 rpm.

The test engine is coupled through a tail shaft to a Dyno Dynamics dynamometer. The primary component of the dynamometer is an electromagnet absorber which applies a load to the engine. As a result it is possible to calculate the power and torque generated varying the engine speed as required by the test procedure. The flow meter used in this study to measure the fuel consumption of the engine was a Micro Motion Elite CMF025 carioles type flow meter. The exhaust gas analyser (EGA) used was an Andros 6241A, 5 gas analyser. The EGA functions in a way that it takes instantaneous readings of a sample of the exhaust gas, which is taken from the exhaust stream. The EGA measures oxygen, carbon dioxide, carbon monoxide and hydrocarbons using a non-dispersive infrared (NDIR) sensor. This model also measures nitrogen oxide using an electrochemical sensor.

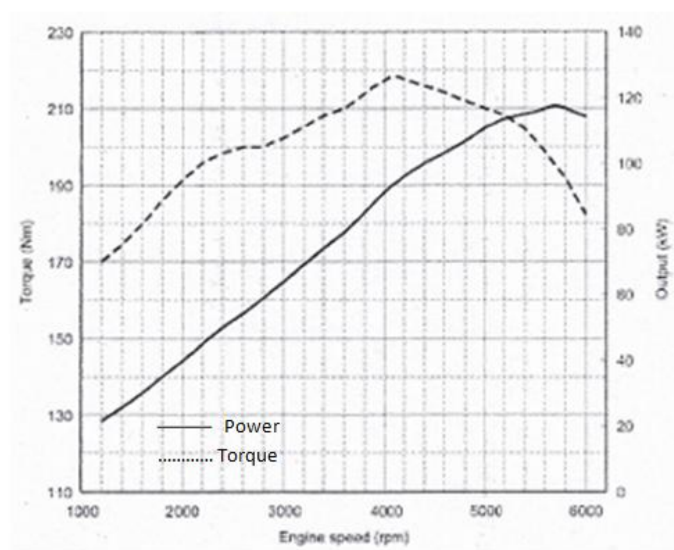

Figure 2: Characteristic curves for 2AZ-FE Engine [6]

Test Procedure

The EPA Motor Vehicle Aftermarket Retrofit Device Evaluation Program was incorporated into the testing [9]. The program states that the test sequences are to be conducted in "back-to-back" fashion. Minimum test requirements are triplicate tests when the vehicle is in baseline condition followed by triplicate tests with the device installed with no vehicle adjustments between tests [9]. The implemented test procedure consisted of triplicate tests without the device, triplicate tests with the device fitted and final triplicate tests without the device. The final test was conducted to prove that it was in fact the device that made the difference and not some underlying factor. The testing period for each test was 30 minutes, therefore a total testing duration of 270 minutes for each device. All testing was conducted at the Central Queensland University's thermodynamics laboratory.

Issues

Before testing the fuel efficiency devices, a dummy test was conducted so that potential issues could be addressed before they had an impact. The potential issues identified include weather conditions and equipment issues. Inconsistent weather conditions could have affected the test results for performance and emissions. An engine performs more efficiently when the air temperature is cooler, therefore rapid changes in ambient temperature and humidity was not acceptable. To keep all results as consistent as possible, testing was only conducted on warm sunny days, where the temperature and humidity were as stable as could reasonably be expected. Testing was usually carried out between 9 am and 3 pm.

The exhaust gas analyser recalibrated automatically regularly to maintain a high level of accuracy of emission measurements. During testing it was realised that the analyser required calibration approximately every 30 minutes. For testing, snapshots were required every 5 minutes of a 30 minute test. Fortunately, the recalibrations did not affect the recording of data as the automatic recalibrations occurred during the 5 minute window. On the couple of occasions where the analyser was calibrating at the 5 minutes period, a later snapshot was taken.

RESULTS AND DISCUSSIONS

Brake Power and Torque

The Dyno Dynamics Dynamometer recorded experimental data for brake power, brake torque, fuel consumption and exhaust emissions for each snapshot taken. The dynamometer supplied data for other parameters including load (kg), air flow (kg/h) and oil temp (^{0}C), however they were not required for the analysis. Line graphs were produced for brake power, brake torque and fuel consumption (Figure 3, Figure 4 and Figure 5 respectively), with all being plotted against time (min). The petrol exhaust emissions (CO emissions) were plotted as "bar" graphs reflecting emission change over time.

At a rated engine speed of 2000 rpm and throttle setting of 50%, the three devices were tested in accordance to the standard procedure used by the EPA. The results indicate that no significant increase in brake power and brake torque was achieved during testing for all three devices.

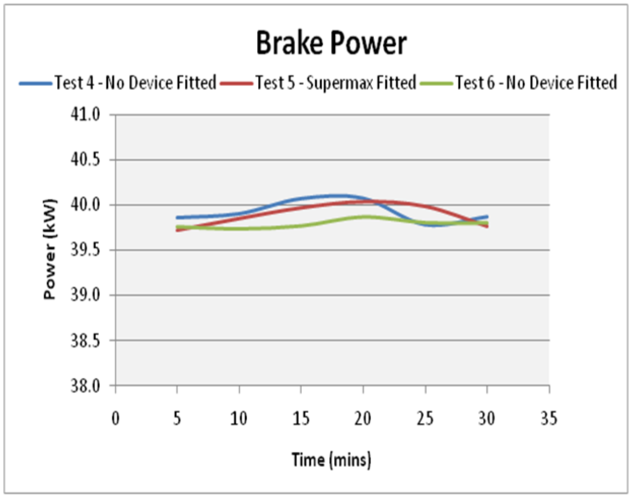

Figure 3: Comparison of Brake Power (Supermax)
(Hiclone and FFC results are not shown).

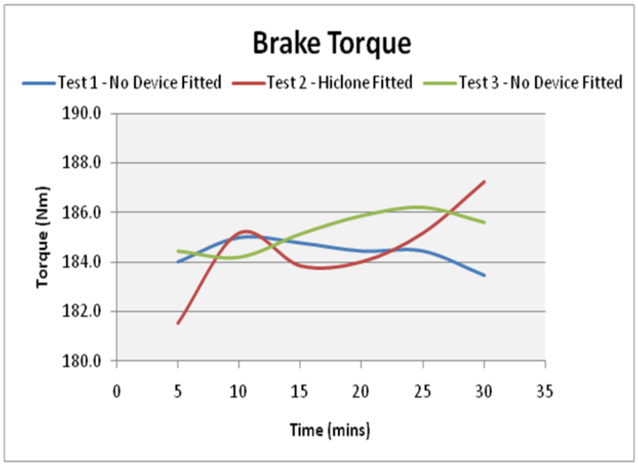

Figure 4: Comparison of Brake Torque (Hiclone)
(Supermax and FFC results are not shown).

For the Hiclone device, Test 2 (Device fitted) has an average increase of 0.39% and 0.077% to Tests 1 and 3 respectively. For the Supermax device, the results obtained indicate an increase and decrease in brake power, shown in Figure 3. Test 5 (Device fitted) had a 0.18% decrease compared to Test 4 (No device fitted) and a slight increase of 0.2% compared to Test 6 (No device fitted). Similar results were obtained for the FFC with average increases of 0.5% and 0.88% for Tests 7 and 9 compared to Test 8 when the device was fitted.

The brake torque results vary by similar percentages as the brake power measurements. This is expected as brake torque and power are directly proportional when the engine speed is fixed. The results recorded during the three tests for the Hiclone device displayed the largest change over the 30 minutes testing period, which can be seen in Figure 4. With the device fitted the results fluctuated between 181.5 Nm and 187.3 Nm, with the second half of the 30 minutes period showing a steady increase. It is hard to predict whether this increase would have continued as an earlier increase turned into a decrease after the 10 minutes period. It has become apparent that the Hiclone device which was installed in the air induction hose of the engine has resulted in an inconsistent intake air flow. This could be as a result of the small modifications that were made to the device fins for it to fit into the air induction hose.

Fuel Consumption

The three fuel efficiency devices that were selected for testing all claimed to reduce fuel efficiency by up to 20%. This is a significant reduction in fuel consumption and therefore should have been quite easy to detect when perusing results. The results obtained for the three selected fuel efficiency devices indicate that there was no significant decrease in fuel consumption.

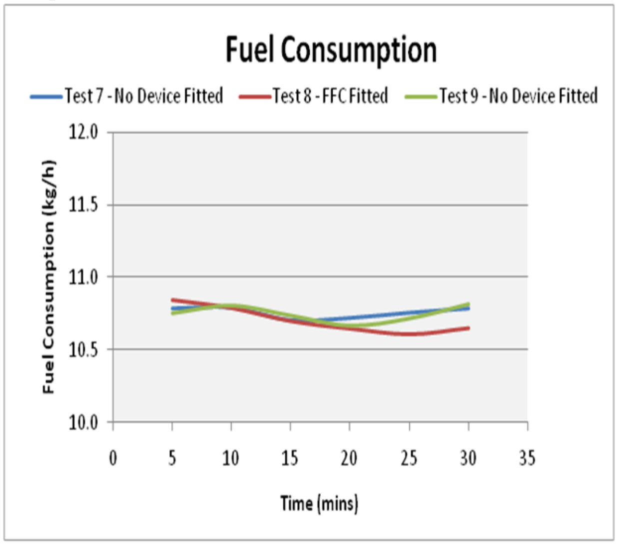

Figure 5: Comparison of Fuel Consumption (FFC)
(Hiclone and Supermax results are not shown).

All results obtained for the Hiclone, Supermax and FFC devices fell within 0.7 kg/h, 0.3 kg/h and 0.2 kg/h windows respectively. The data recorded for the FFC device showed promising result as Figure 5 displays. The graph in question shows that for the first 17-18 minutes the fuel consumption for all three tests was gradually decreasing. However, after this interval in Tests 7 and 9 it begins to rise again, while in Test 8 it continues to decrease. At the 25 minutes interval, the curve which represents Test 8 shows a slight increase. The reduction in fuel consumption over the 30 minutes testing period is minimal and therefore no positive impact by the FFC device is made.

Exhaust Emissions

The analysis of combustion products was quite difficult as the low cost exhaust gas analyser used was not expected to give perfect results. Emission analysis is much easier when the air-fuel ratio is varying with an increasing engine speed. As a result, there was no possible method to plot the data with respect to the air-fuel ratio as it was expected to remain the same (within a small margin) for all tests conducted. This judgement was the same for all petrol exhausts emissions, unless the three fuel efficiency devices impacted in some way.

No significant trends were obtained for the three devices for carbon dioxide, carbon monoxide, nitrogen oxides and hydrocarbon emissions. Results showed promising trend between the first two tests for the Supermax and Hiclone devices. For the Supermax device, the average reduction between Tests 4 and 5 was 10.06%, shown in Figure 6. The data which was recorded for the Hiclone device provided similar trends to the Supermax device, as an average reduction of 6.76% was measured between Tests 1 and 2. The purpose of the final test without the device was to ensure that it was actually the device which was making an impact and not some underlying factor. The results for Test 3 (Hiclone) and Test 6 (Supermax) were expected to be similar to Tests 1 and 4; however a trend was evident between each 5 minutes time interval where another slight decrease occurred. In theory a reduction of CO emissions between the first two tests should coincide with an increase in CO_2 emissions, however this did not occur.

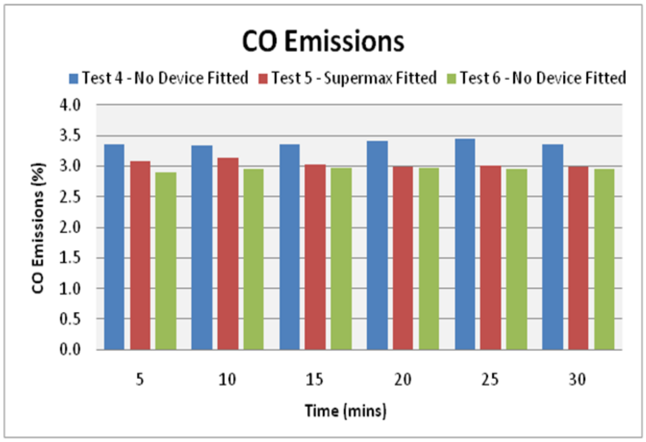

Figure 6: Comparison of Carbon Monoxide Emissions (Supermax)

(Hiclone and FFC results are not shown)

CONCLUSION AND RECOMMENDATION

This study has provided an appreciation and understanding of the effects of fuel efficiency devices when fitted to an internal combustion engine and the operation of internal combustion engines and dynamometers.

The results obtained are not conclusive and should serve as a motivation for further testing in order to find a definitive conclusion. It is recommended that further testing be carried out using the standard test procedure implemented by the EPA and that a more reliable set of equipment be used. Possible modifications to the test procedure whilst still complying with the standard one could include a longer testing time for each device. This was not possible for this study due to the limited hours of laboratory use; however further testing would be beneficial for performance and exhaust emission assessment.

This study investigated the effects of fuel efficiency devices in "highway" conditions; therefore further testing could be carried out to represent "city" driving. This could entail running tests where the engine speed is varying between 1000 and 5900 rpm. A more detailed performance and exhaust emissions discussion could then be completed and the effects of an increasing/decreasing air-fuel ratio be noted.

Overall, this study has made comparisons between the performance and exhaust emissions when the laboratory engine was in baseline condition and when the fuel efficiency devices were installed. No significant changes were obtained as discussed above and therefore purchasing the devices is not recommended.

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