International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 5 No. 5, May, 2015

Comparative Study on Exhaust Emission and Engine Performance of Single Cylinder Spark-Ignited Engine Operated On Gasoline and Natural Gas

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ABSTRACT

Emission and performance of a single cylinder spark ignited engine fuelled with both natural gas and gasoline were measured at full load and top gear performance up to 8500 rpm. Exhaust emission for both gasoline and natural gas was analysed at idle speed and average speed of 40 – 90 km/hr. The tests have shown that the natural gas fuelled engine gives a complete combustion, which decrease 99.6 % of carbon monoxide and 72.5 % of unburned hydrocarbon at a speed of 70 km/hr compares to gasoline fuel. However, lower calorific value and burning velocity of natural gas reduces engine power by 15%.

Keywords: *Exhaust emission, Engine performance, Combustion, Natural gas, Spark-ignited engine*

1. INTRODUCTION

The importance of air pollution and environmental protection has drawn much attention in Malaysia since global environmental problems first emerged as a common worldwide concern at the United Nations Conference on Human Environment in 1972. In Malaysia, urban air pollution is reaching a critical level as witnessed during the recent haze crisis. Average emission of fine particulates is 77µ/m^3. This figure is above 50 ug/m^3 acceptable standard followed by the Department of Environment for Malaysia. The urban transportation and industrial activities in Malaysia have aggravated the problem. The Federal Territory of Kuala Lumpur has the highest growth rate in the field of transportation, utilities and manufacturing activities in the country (Department of Transport Malaysia, 2011). The vehicle population has been increasing tremendously, thus aggravating the sulphur and lead content in the atmosphere (Department of Environment Malaysia, 2011, Jakapong, P. and Chumnong, S., 2013).

It is estimated that in 2010 the combined air pollutant emission load was 1,681,440 metric tonnes of carbon monoxide (CO); 740,006 metric tonnes of nitrogen dioxides (NO_2); 174,820 metric tonnes of sulphur dioxide (SO_2) and 26,964 metric tonnes of particulate matter (PM). A comparison of the combined air pollutant emission load in 2009 and 2010 is shown in Fig. 1. In 2010, there was an increase in emission load for CO and SO_2 with an increase of 3.71 % and 1.69 % respectively compared to 2009. Meanwhile, there was 2.16 % decrease in NO_2 emission load and 2.75 % decrease in PM emission load in 2010 compared to 2009 (Department of Environment Malaysia, 2011).

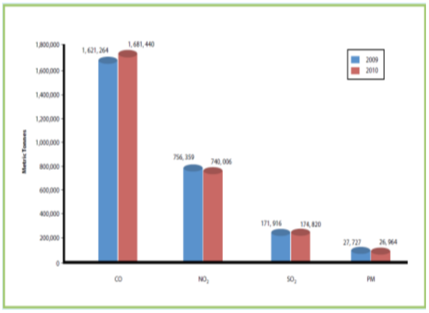

Fig.1: Malaysia: Air Pollutant Emission Load from All Sources, 2009-2010

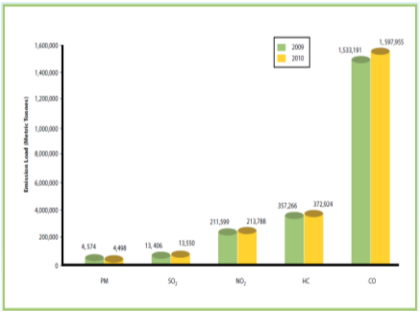

Fig. 2: Malaysia: Air Pollutant Emission Load from Motor Vehicles, 2009-2010

The estimated annual air pollutant emission loads of HC, CO, PM, NO_2 and SO_2 from motor vehicles for 2009 and 2010 is shown in Fig. 2. In 2010, the emission load of HC and CO was estimated to be 372,924 metric tonnes and 1,597,955 metric tonnes respectively. Except for PM, there was an increase in emission load for HC, CO, SO_2 and NO_2 as compared to 2009.

These polluting substances lead to the production of smog that destroys sensitive tissues (in people, animals and plants), the formation of inhalable carcinogenic particles, reduced lung function and ultimately responsible for many untimely deaths every year. Furthermore, air pollutant also will trap excess heat contributing to global warming and climate change, rising sea levels, changes in vegetation and increase in the frequency of severe weather events. 1997 haze episode in Malaysia recorded 285,227 asthma attacks, 118,804 cases of bronchitis in children, 3889 cases of chronic bronchitis in adults, 2003 respiratory hospital admission, 26,864 emergency room visits, and 5,000,760 restricted activity days(Nasir M.H. et al., 2000, Afroz R. et al., 2003).

In order to reduce air pollution caused by vehicle, Malaysia government support PETRONAS to introduce Natural Gas Vehicle (NGV) program by providing incentives Hamid, H.A. and Ahmad, A.S., 1996, Jeff M.A., 1996). NGV, which produces much cleaner burning, will reduce the emission of unburned hydrocarbon and carbon monoxide, which is normally produced by gasoline driven cars (Jones K. et al., 1986, Arizipe L. et al., 1992, Djoke K., 1996). Europe was also introduced NGV programmed to reduce its air pollution in big cities. In addition to that European governments have developed tax reduction to foster NGV application (Engerer H. and Horn M., 2010), whereas Thailand choose to adopt the use of NGV to reduce the emission of greenhouse gaseous (Jakapong, P. and Chumnong, S., 2013).

Gasoline powered vehicles produce oxides of nitrogen (NOx) that when combined with volatile organic compounds (VOC's) which are produced by trees naturally, will react with sunlight in the lower atmosphere to form ozone, a primary constituent of smog. CNG powered vehicles are considered as clean system which emit 85 % less NOx, 70 % less reactive hydrocarbons, and 74 % less carbon monoxide than similar gasoline powered vehicles (Maxwell T.T and Jones J.C., 1995, Suga t., et at., 1997). The use of CNG-fuel vehicles significantly reduces emissions of ozone precursors (Yamamota, Y., Sato, K.T, 1994).

A significant change of energy policies has emerged in many nations throughout the world, including Malaysia. These new policies and the programs to implement them, herald the beginning of global transition away from oil as the dominant transportation fuel and toward the use of cleaner, more abundant and eventually sustainable energy resources (Peter B. and Frances N., 1995). Natural gas has proven to be cleaner, cheaper, safer and more domestically abundant than gasoline or other transportation fuels (Jeff M.A., 1996). Propelled by favorable government policies and aided positive economic and environmental attributes, natural gas vehicles have an impressive growth in Malaysia. Bi-fuel motorcycle is a new technology introduced to alleviate emission problems and became an option for the present system available. This motorcycle can run either with gasoline or natural gas and offers mono flexibility in term of fuel usage. The objective of this work is therefore to compare the emission and engine performance of bi-fuel motorcycle fuelled with gasoline and natural gas under idle and average speed of 40 to 90 km/hr.

The number of motorcycle use has rapidly expanded over past several years, especially in the urban city as the Federal Territory of Kuala Lumpur. In Malaysia, nearly five million units or over half of the motor vehicles in Malaysia are motorcycles. The increasing number of motor vehicles is from 19,016,782 in 2009 to 21.25 million in 2011 with the highest concentration (4,914,992 units) of vehicle population in the Federal Territory, Kuala Lumpur (Department of Transport Malaysia, 2011).

2. MATERIALS AND EXPERIMENTAL

2.1. Experimental Equipment

The motorcycle used for this study is KRISS 110, 4-stroke single cylinder. The motorcycle fuel system has been modified so that it can operate on either petrol or natural gas. The specifications of the motorcycle are listed in Table 1.

2.2. Exhaust Emission Tests Standards

Emission test were carried out in accordance with the ISO 3929, ISO 6460 and ISO/TR 6970 test procedures. The exhaust emission for both gasoline and natural gas was analysed at idle speed and average speed of 40 – 90 km/hr. The motorcycle was tested on a chassis dynamometer at various constant speeds: 0, 40 to 90 km/hr, respectively. Horiba MEXA 324J.Infrared emission analyser was used to detect CO and HC emission while ENAREC 2000 emission analyser was used to detect N_{Ox}.

Table 1: The Specification of MODENASS KRISS 110cc Motorcycle

Type		4 st, 1 cyl, SOHC
Bore x stroke	(mm)	53.0 x 50.6
Displacement	(cm^3)	111
Compression ratio		9.3
Carburetor Type		KEIHIN PB18 X 1
Diameter of throttle valve	Mm	18
Diameter of venturi	Mm	18
Type of choke valve		Butterfly
Lubrication system		Forced lub. Wet
Engine oil	SAE Grade	1.1(L)
Cooling system		Air cooled
Ignition system		Magneto to CDI
Ignition timing angle	(°/rpm)	6.5 BTDC /1200 ~27 BTDC / 4000
Spark plug type/gap	0.7 (mm)	NGK C6HAS

(Modenas KRISS 110 Operating Manual)

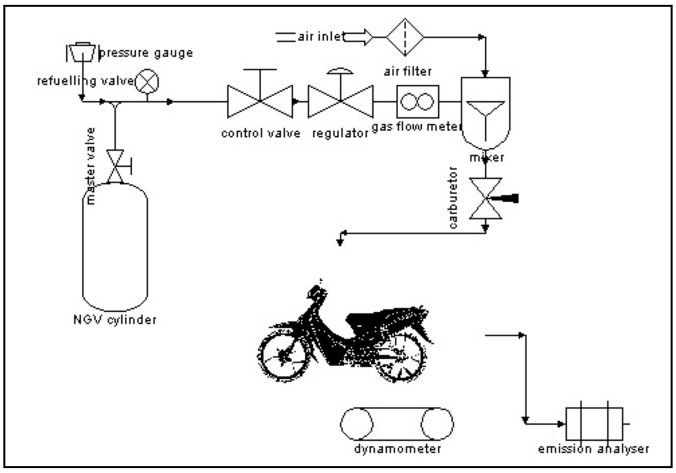

Fig 3. Schematic Diagram of the Bi-fuel Motorcycle Test

Test rig

The experimental rig comprise of an engine of MODENAS, KRISS 110 cc motorcycle, a chassis dynamometer, emission analyzer and a data acquisition system. A data acquisition system, which is a data translation converter and a dedicated computer, are used to record data such as engine speed, torque, power, exhaust temperature and engine temperature.

The schematic diagram of the experimental equipment is shown in Fig. 3

Combustion Fuel

Natural gas and gasoline (PETRONAS, Primas PX2) have been used as operating fuel to run the bi-fuel motorcycle. The composition of the natural gas and the specification of gasoline are shown in Table 2 and Table 3 respectively.

Table 2: Natural Gas Composition

Component	Mol %
C_{6+}	0.07
C_3	0.90
iC_4	0.29
nC_4	0.13
iC_5	0.07
N_2	0.68
C_1	93.07
CO_2	1.10
C_2	3.70
Compressibility	0.9977
Density	0.7404 kg/sm^3
Relative Density	0.6042
Molecular Weight	17.4663
Gross Calorie Value	39.20 MJ/sm^3

Table 3: Gasoline Specification

Description	Value
Density @ 15^{0}C, kg/l	0.733
Research Octane Number (RON), g/l	97.0
Lead Content, kPa	0.008
Reid Vapour Pressure, %wt	62
Total Sulphur	Trace
Distillation	
50% evaporated, ^{0}C	105
90% evaporated, ^{0}C	152
Colour	Yellow

3. RESULTS AND DISCUSSION

The test results of exhaust gases emission are summarised in Figs. 4, 5, 6, 7 and 8.

Carbon Monoxide (CO) Emissions

It was found that at an idle speed, CO emission from natural gas powered motorcycle was at an average of 0.02 % vol., which is equivalent to 99.7% decrease for gasoline powered (3.998 %vol.). Whereas at constant speeds of 40 to 90 km/hr, the amount of CO from natural gas powered motorcycle was between 0.02-0.06% due to good mixing of natural gas with air and consequently lead to complete combustion for natural gas compared with gasoline. Therefore, the percentage of CO emission is almost zero percent. Figs. 4 and 5 illustrate the test results for idle speed exhaust emission and average CO emission respectively. Similar results were reported by Karavalakis et al., 2012, Poala H.B.Z. and Jose R.S., 2009, Dondero L. and Goldemberg J., 2005, Mello P. et al., 2006, Maxwell T.T and Jones J.C., 1995, Yamamota Y. and Sato K.T., 1994.

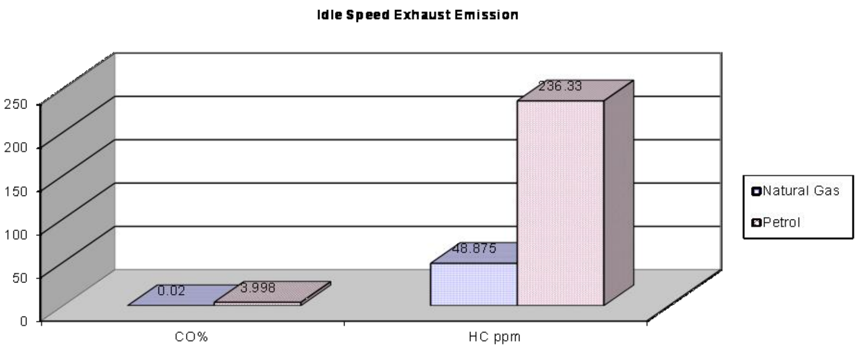

Fig. 4: Idle Speed Exhausts Emission

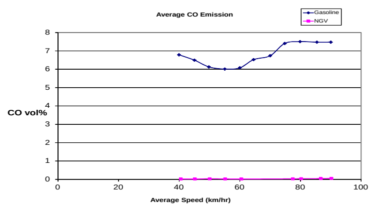

Fig. 5: Average Carbon Monoxide Emission

Unburned Hydrocarbon (UHC) Emissions

The amount of UHC emitted by natural gas motorcycle was 79.3 % lower than gasoline fuelled motorcycle, equivalent to 48.875 vol. ppm at an idle speed. Similar result was obtained for constant speed of 40 km/hr to 90 km/hr where the natural gas powered motorcycle produces UHC at approximately 48 ppm as shown by Fig. 6. The amount of UHC emitted from natural gas powered motorcycle is lower because of the readiness and ability of of natural gas to mix well with air which ensures the completeness of the combustion. This results match with the finding reported by Karavalakis G. et al., 2012, Dondero L. and Goldemberg J., 2005, Mello P. et al., 2006.

Nitrogen Oxides (Nox) Emissions

Fig. 7 illustrates the emission of NO_X produced by bi-fuel motorcycle at different engine speed. The emission of NO_X profile for gasoline showed increment with the increasing of engine speed. Natural gas fuelled motorcycle is really effective to eliminate nitrogen oxides. According to the testing on bi-fuel motorcycle using natural gas, it has clearly

shown that nitrogen oxides was totally eliminates when operating using natural gas compared to gasoline at various operating conditions. ENAREC 2000 emission analyser used to detect nitrogen oxides does not detect any presence of NOx during bi-fuel motorcycle operation while using natural gas compared to an average of 6.8 vol. ppm at different engine speed when operating using gasoline.

Fig. 8 shows the relationship of engine oil temperature and emission of NO_X. NO_X emission increases steadily with increasing engine temperature. Engine oil temperature for gasoline-fuelled motorcycle is higher than the engine oil temperature for natural gas fuelled for the similar motorcycle. It shows that the temperature in the combustion chamber is higher when using gasoline as a fuel. This is because gasoline has much higher calorific value compared to natural gas. The impact of this known fact is more significant in relation to the formation of NO_X. The higher operating temperature when using gasoline encourages much easier formation of NO_X compared to when using natural gas. Karavalakis G. at al., 2012, Dondero L. and Goldemberg J., 2005 also reported similar findings.

Combustion Efficiency

Fig. 9 illustrates the relationship of combustion efficiency for both, gasoline and natural produced during the test on various engine speeds. At low engine speed, the combustion of petrol fuel gives unsteady and poor combustion efficiency. The combustion efficiency for this fuel increases as the engine speed increases. The combustion of natural gas fuel however shows a constant trend. This is due to the characteristics of the fuel itself. Unlike gasoline, which must be vaporized before ignition, natural gas is already in gaseous form when it entering the combustion chamber. As the intake valve opens, the gas enters the combustion chamber, where it is ignited easily to power the motorcycle.

Fig. 10 shows profile of combustion efficiency at different engine temperature for gasoline and natural gas. This figure shows the relationship of combustion efficiency with combustion temperature in the engine. Gasoline fuelled motorcycle shows unsteady combustion efficiency at different engine temperature. Natural gas as before, gives constant high combustion efficiency. Figs. 9 and 10 matched each other when cross-referred each other in terms of combustion efficiency, where the combustion efficiency of natural gas fuel is far better than gasoline fuelled motorcycle. Result of this study is well agreed with finding made by Yamamota Y. and Sato K.T., 1994.

Engine Oil Temperature

Fig. 11 shows the engine oil temperature in relation to different fuelling system either using gasoline or natural gas. Engine oil temperature for gasoline fuelled motorcycle is higher (85.5 ºC) than the engine oil for natural gas fuelled for the similar motorcycle. It shows that the temperature in the combustion chamber is higher when using gasoline as a fuel. This is simply because gasoline has much higher calorific value compared to natural gas. The impact of this fact is more significant. The higher operating temperature when using gasoline encouraged much easier formation of NOx as compared to when using natural gas as a fuel for the engine.

Engine Performance

Fig. 12 shows the maximum engine power as a function of engine speed for both fuels. The results are obtained at wide-open–throttle with manufacturer setting ignition timing. During the operation using natural gas, the power was reduced by approximately 15% at high engine speed. This power loss is due to the displacement of air by natural gas and low burning velocity of natural gas compared to gasoline. Despite of having high octane rating number of 30 compared to gasoline of only 92 to 98, due to prior setting of compression ratio for gasoline system, inherent performance benefit of natural gas which is high compression ratio are lost. As the engine speed increase, the engine power is further decreasing due to inappropriate design of mixer system. Although natural gas is having high octane rating and the engine could operate at a compression ratio up to 16:1 without “knock” it is still unable to be achieved that level due to the limitation on engine compression ratio capability which was designed at 9.3:1 for gasoline. Therefore, natural gas powered motorcycle requires advance spark ignition timing compared to gasoline system in order to utilise the high compression ratio and high octane rating characteristics of natural gas (Dondera L. and Goldemberg J., 2005).

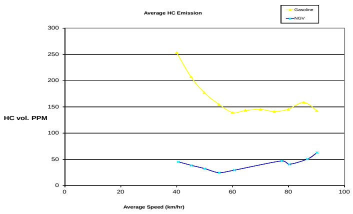

Fig. 6: Average Hydrocarbon Emission

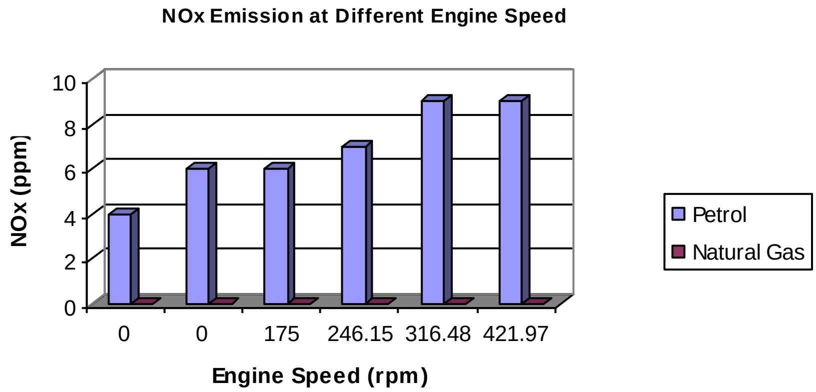

Fig. 7: Nox Emission at Different Engine Speed

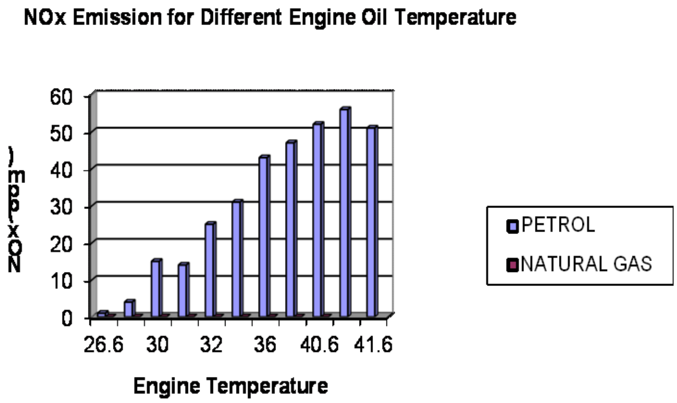

Fig. 8: NOx Emission at Different Lubricating Oil Temperature

ISSN: 2049-3444

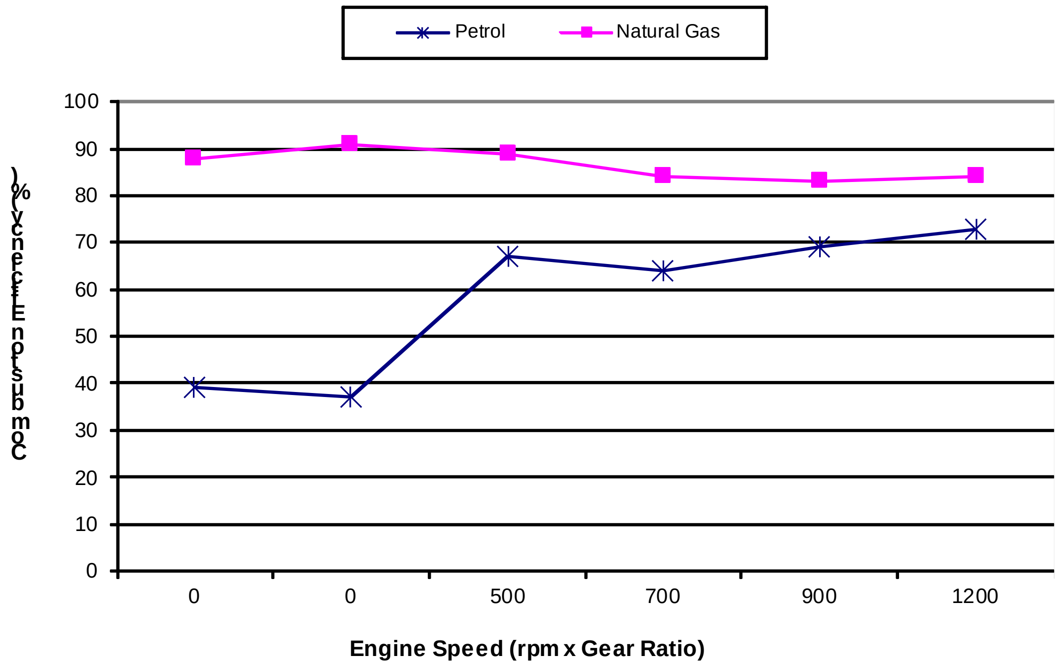

Fig. 9: Combustion Efficiency at Different Engine Speed

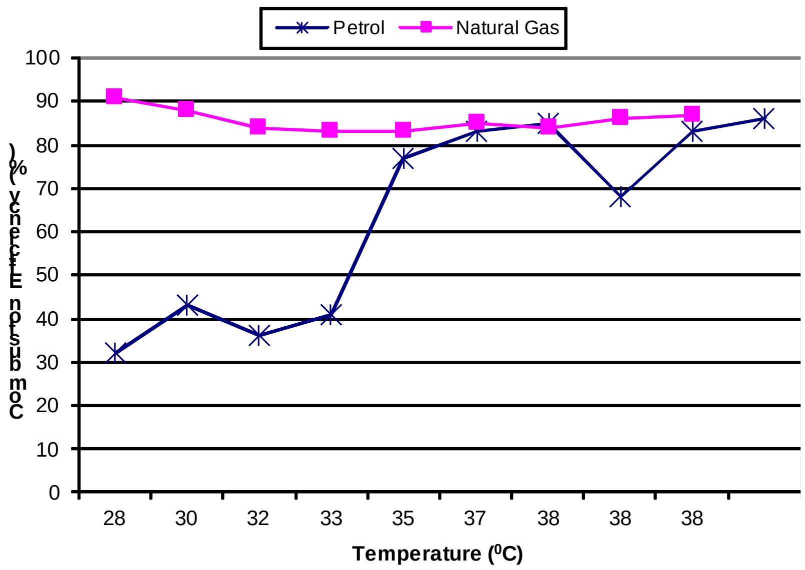

Fig. 10: Combustion Efficiency at Different Engine Temperature

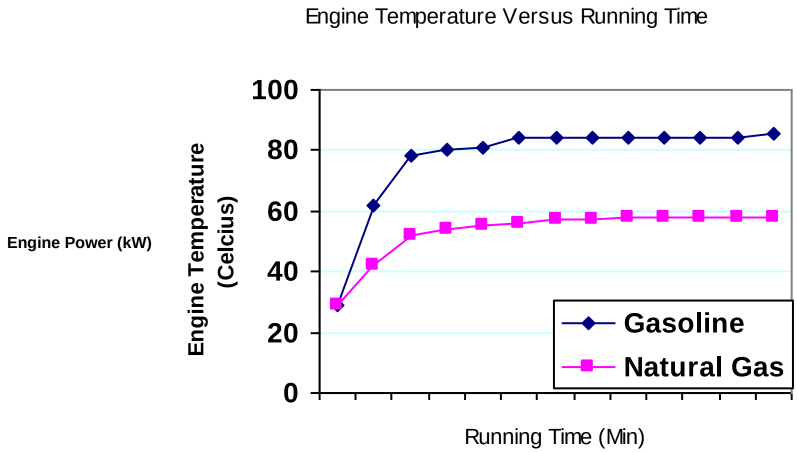

Fig. 11: Lubricating oil temperature over running time

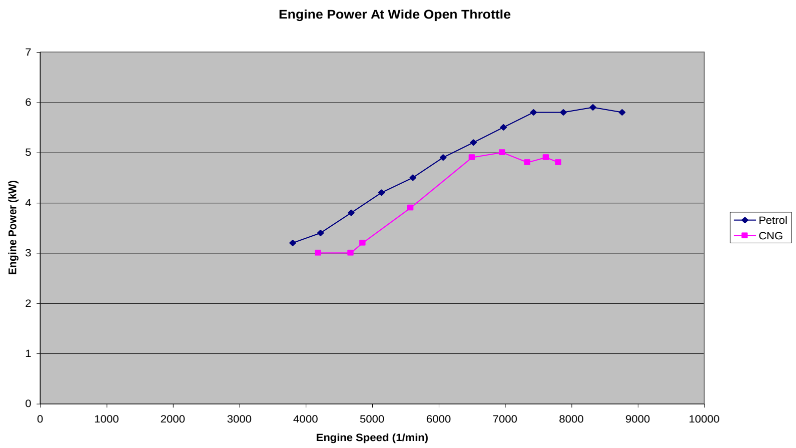

Fig.12: Engine power against engine speed

4. CONCLUSION

The test result shows very favourable indication for the use of natural gas as a fuel for motorcycle. Although natural gas powered motorcycle has less power output but this newly developed technology is capable of eliminating nitrogen oxides and gives a significant decrease of CO and UHC emission with high combustion efficiency. This is partly contributed by gaseous phase physical nature of natural that mix well with aspirated combustion air at the mixer. Thus, combustion of natural gas provide complete burning of the fuel itself resulting less exhaust gas emission emitted to the atmosphere. Since the air pollution is a major concern today and leads to annihilation of an environment and human health especially in densely populated area and congested city centres, the natural gas powered motorcycle is one of the measures to solve this problem.

ACKNOWLEDGEMENT

The authors would like to express gratitude to Universiti Teknologi Malaysia, Ministry of Higher Education (MOHE), for giving a research grant number 01H63. We would also like to thank all colleagues and friends for the continuous support, and to express our gratitude to the Faculty of Petroleum and Renewable Energy Engineering for providing the authors the chance to perform the study.

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