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BI-FUEL NGVM ENGINE EMISSION RESULTS BASED ON NON-LOADED SYSTEM OPERATION

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ABSTRACT

Alternative fuels for the internal combustion engines are introduced as an improved fuel over mainstream conventional fuels such as petrol and diesel. Compressed Natural Gas (CNG) is the most successful and widely used alternative fuels that helps mitigate emission problem caused by vehicles. Mainstream fuelled vehicles are fitted with a conversion kit to enable the operation with CNG, these converted vehicles are called Natural Gas Vehicles. A bi-fuel engine test rig was fabricated using a 1500cc 12 Valve engine fitted with a Landi Renzo conversion kit enabling operations on petrol and natural gas. This test rig was used to conduct experiments to obtain the fuel consumption and the corresponding exhaust emission quality. The results obtained were compared with the actual data of NGV taxi fitted with Tartarini conversion kit for validation purpose. The findings from this experimental rig are used as a comparison between the use of petrol and natural gas as fuel for vehicles. The results clearly prove that the use of natural gas provides improved exhaust emission at lower cost.

Keywords: *Alternative fuel, NGV, bi-fuel engine, fuel consumption, exhaust emission, NGV conversion kits.*

1.0 INTRODUCTION

The introduction of Compressed Natural Gas (CNG) as an alternative fuel in Malaysia was supported by various factors that include; the abundant local natural gas reserve, the availability of Peninsular Gas Utilization distribution system (PGU) infrastructure, and the clean burning property of natural gas. The typical petrol operated mono-fuel vehicle is fitted with an imported conversion kit enabling bi-fuel capabilities of petrol and CNG. Two authorised conversion kit installers in Malaysia are Tractors Malaysia and OGPP that supply Tartarini NGV and Landi Renzo conversion kits respectively. These imported Natural Gas Vehicle (NGV) conversion kits are exempted from import duty and sales tax to encourage vehicle user to convert the engine into bi-fuel system. Road tax is reduced from the existing level by 50% for Mono-fuel (operating only on one fuel i.e. natural gas) and 25% for bi-fuel (operating on two types of fuel, one at a time) and dual-fuel (operating on both fuels forming a mixture of fuel).

The Petronas is the only fuel retailer that offers CNG to NGV users. There are two types of NGV station called a “mother-station” and a “daughter-station”. The “mother-station” type has a natural gas pipeline to its premises where the gas is compressed to 3600 psig via three stage compressor system and stored in a cascading storage system. The cascading storage systems are made portable enabling it to be

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moved to the “daughter-station”. The daughter-station supplies customers from the cascading storage system charged at the “mother-station”. This is done by transferring the CNG from the cascading storage to the vehicle’s onboard storage cylinder thru the CNG dispenser unit.

Petrol is priced at RM 2.70 per litre whereas one litre of natural gas is priced at RM 0.68, making it the cheapest commercial fuel available in the market. The litre measurement used to describe the CNG pricing is proven by calculations shown in the appendix that it is actually litres energy equivalent to petrol. Due to the energy equivalent factor, the energy within the natural gas bought for RM 0.68 is the same as the energy content within 1 litre of petrol at RM 2.70. It is known from the reference that 1 litre of petrol has approximately 30.676 MJ of energy [1]. The energy content of Malaysian natural gas is 1053 Btu per cubic ft [2] which translates to 0.9574 MJ per mol of natural gas. From experiments conducted, one 55 litre water capacity tank would accommodate approximately RM 8.43 worth of natural gas. The energy content of this fully charged tank is predicted as 380 MJ by the energy content calculations (shown in appendix A). The value is then divided with the energy content per mol of natural gas to obatain 397 moles of nattural gas per charge of a 55 litre cylinder. The petrol cost for similar amount of energy would sum up to RM 33.45, giving savings up to RM 25.00 for every charge of the NGV tank.

The amount of moles within the NGV cylinder as predicted by the energy content calculation is validated using PV relations based on thermodynamic principles. The generalized correlation for gases by Pitzer [3], Benedict/Webb/Rubin [4], and results obtained from Friend *et al* [5] are compared to obtain the best prediction of mol content within the storage cylinder. The findings by Friend et al, is comparatively the most accurate method and proves similar value with the Benedict/Webb/Rubin method until the designed CNG operating pressure of 3000 psig. The Pitzer correlation deviates greatly at 353 K and 3000 psig from both friend et al and Benedict/Webb/Rubin methods.

Referring to MS 1096, the cylinder temperature would rise up to 80 ^{o}C (353 K) during charging [6]. This internal temperature increase during charging depends on the cylinder’s material of construction that has different heat dissipation abilities. The storage capacity of a cylinder is inversely related to the internal temperature during fast fill. CNG cylinder constructed primarily from steel (NGV Type 2) is employed on the system understudy to provide the most cost effective storage capabilities [7]. The graph displayed by Friend *et al* [5] and Benedict Webb Rubin[4] in Figure 1 clearly shows that 400 moles within the cylinder would generate an internal pressure of 2700 psig at 353 K. This value corresponds to the value obtained during the experimental charging done with an empty cylinder. The storage internal pressure is unable to reach the designed operating pressure of 3000 psig during charging due to the temperature compensating mechanism included in the CNG dispenser. Currently most commercially available CNG dispensers rely on a mathematical model or algorithm utilizing the measured temperature of the gas flowing in the dispenser to determine full charge pressure [7]. This safety mechanism helps avoid extreme internal pressure build up caused by heat within the vehicle during extreme weather.

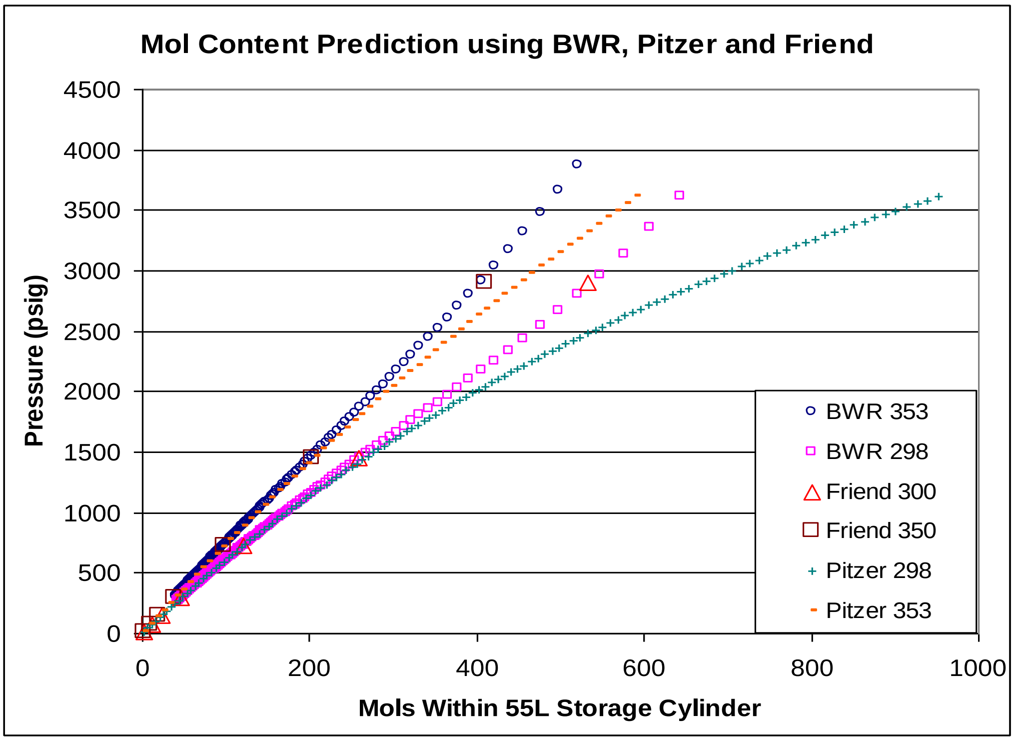


Figure 1 Comparison between Mol content of Natural Gas within Storage Cylinder at 298.15 K and 363.15 K Internal Temperature

Apart from these calculations conducted to estimate the gas content within the cylinder, the fuel consumption and the corresponding exhaust emission are attained through experiments conducted on the bi-fuel test rig. A 1.5 litre 12 Valve Carburettor Proton refurbished engine was serviced and fitted with a newly imported Landi Renzo conversion kit to form the bi-fuel engine test rig. This rig helps to establish a comprehensive understanding on the existing bi-fuel engine system widely installed on local taxis. Related research on the effect of various manifold absolute pressures and air flowrates on throttle body injection mixer in compressed Natural Gas (CNG) triggers similar interests in this particular study [9].

1.1 THE BI-FUEL ENGINE TEST RIG

The engine test rig has three mounting points that are made adjustable in both horizontal and vertical direction to aid the alignment of the engine onboard the rig. These movable mounting points would allow the engine rig to cater for other engines with similar size. The four poles around the main structure are designed to hold the closure panel to ensure safety of operator from the moving parts of the engine. Wheels are attached to the rig to ease manoeuvring and to aid the dampening of the engine vibration during operation. The rig metal structure is coated with epoxy (powder coating) to avoid corrosion caused by extreme working conditions. The installation of the NGV fuel system was based on the MS 1096 and NFPA 52.

Graphical representations of the main structure used to support the engine and other equipments are shown in Figure 2. Two separate skids are made to hold the NGV storage cylinder and the engine, respectively. Figure 3.0 displays the control panel used to hold other components such as the petrol tank, the switches and the sensors in place. Figure 4.0 depicts the bi-fuel system where the petrol from the tank is drawn and sent to the carburettor through a petrol solenoid valve. The return hose from the petrol pump is used to send access petrol to the storage tank during the NGV operation. The NGV system can be seen where the high pressure CNG is sent to the pressure regulator via high pressure tubing. Low pressure natural gas from the pressure regulator is then sent to the mixer beneath the air filter using a low pressure hose. Figure 5 presents the rig setup equipped with closure panels and extended exhaust pipe for operation.

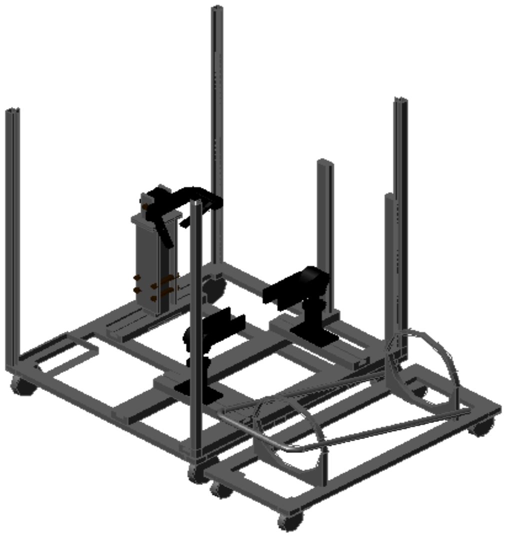


Figure 2: Main Engine Mounting Frame

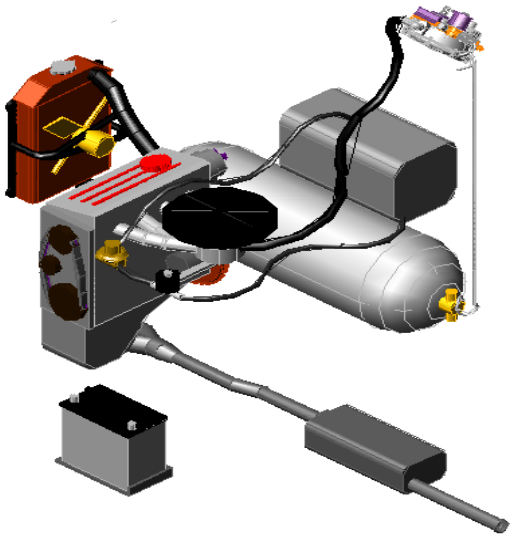


Figure 4: Bi-fuel Fuel Systems

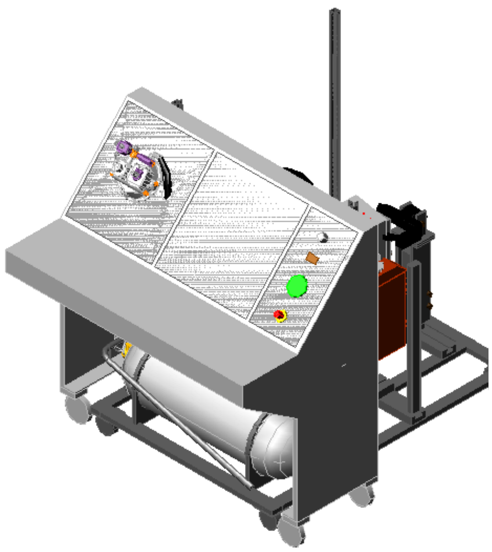


Figure 3: Test Rig Equipped with Control Panel

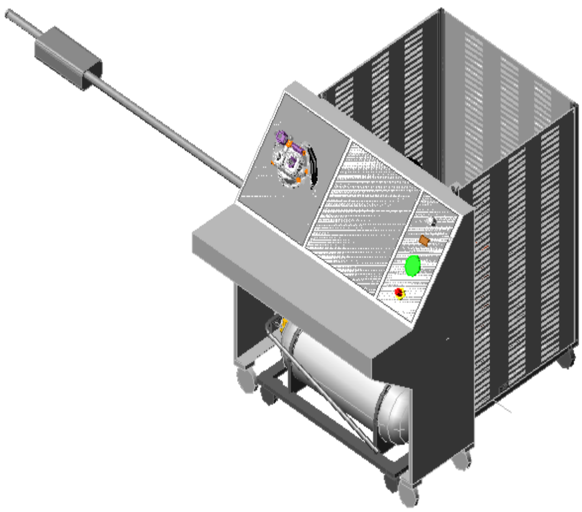
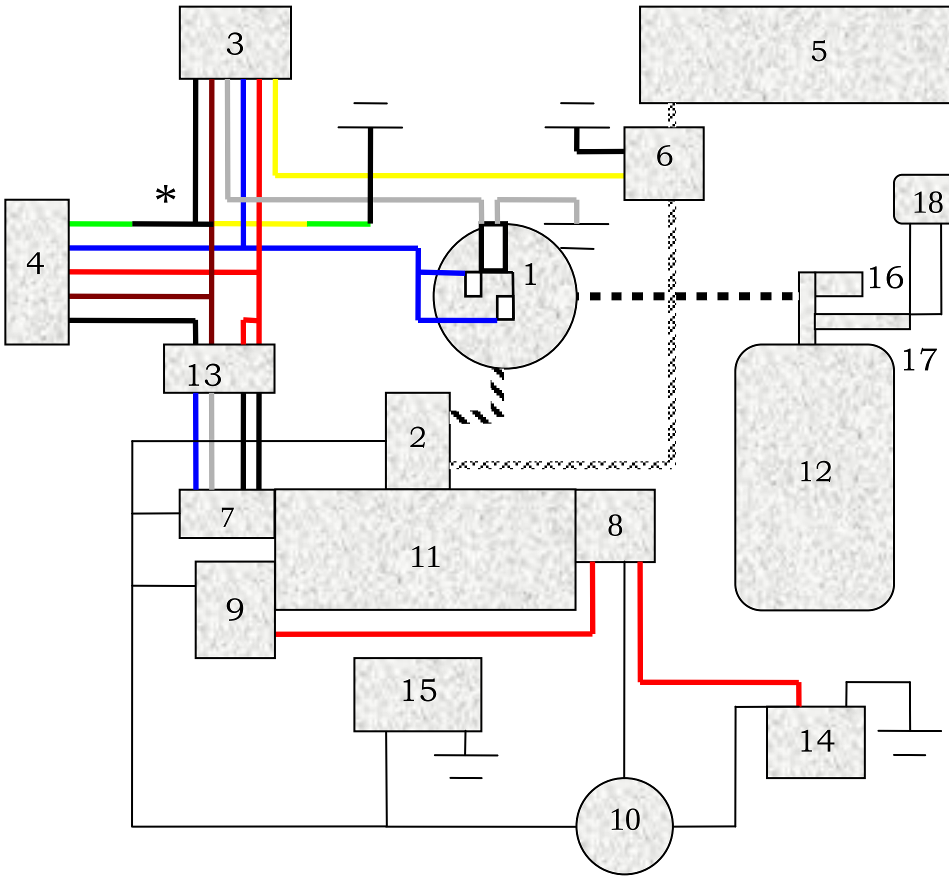


Figure 5: Engine Test Rig for Operation

The engine components were assembled and wired according to Figure 6. When the ignition key is turned to I.G point (ignition - engine starting position), the current from the battery will be supplied to the various components such as the carburettor, the radiator the fan, the spark distributor, and the alternator. The voltage is magnified by the ignition coil at the spark distributor to provide suitable voltage for the operation of spark plug. The distributor provides the spark for the combustion to take place according to the engines preset firing order. The current supplied to the petrol solenoid within the carburettor will allow fuel from the petrol pump to enter the carburettor to form combustible mixture with air. The fuel from the petrol tank is drawn by the petrol pump actuated by the movement of the cam shaft caused by the movement of pistons. Excess petrol from the petrol pump will be sent to the petrol tank thru the fuel return line. The alternator is used to recharge the battery and to supply power to other components of the car, such as car lamp and radio which are not relevant in this study.

When the ignition is turned to start, the current from the battery is supplied to the starter motor which cranks the engine. This will initiate the four stroke combustion cycles (intake, compression, power, exhaust) within the engine block, which is perpetual depending on the supply of fuel, air and electric current. The engine is turned off by cutting the current supply from the battery through the ignition key. The distributor is unable to supply current to form spark within the combustion chamber and caused the petrol solenoid to block the petrol from entering the carburettor. The conversion kit employed on this test rig is only suitable for the carburetion type internal combustion engine. The conversion kit produced by Landi Renzo comprises of a fuel selector switch, step 51 (spark advancer), mixer, pressure regulator and petrol solenoid. The electrical wiring for the conversion kit is shown in the Figure 6.0. The complete assembled conversion kit would enable the operator to switch between fuels through the fuel selector switch with ease.

The petrol solenoid will block the flow of the petrol to the carburettor while current is supplied to open the built in NGV solenoid valve on the pressure regulator, to permit gas flow from the storage tank. High pressure tubing is used to channel the CNG from the storage cylinder to the pressure regulator. At the regulator, gas is regulated according to the requirement of the engine and sent to the mixer through the low pressure tubing. The natural gas fuel demand of the engine is sensed using the vacuum pressure generated by the air flow through the mixer. This vacuum pressure generated by the mixer acts on the 3^{rd} stage diaphragm of the regulator to provide greater fuel flowrate. The spark advancer is activated during the engine operation with gas to alter the spark sequence to suit the combustion of CNG, with its respective variation of petrol intake. The mixer placed beneath the air filter not only detects fuel flow but also promotes the mixing between natural gas and air to improve combustion.



No	Component	No	Component
1	*Pressure Regulator*	2	*Carburettor*
3	*Fuel Selector Switch*	4	*Spark Timing Advancer*
5	*Petrol Tank*	6	*Petrol Solenoid*
7	*Spark Distributor*	8	*Starter Motor*
9	*Alternator*	10	*Ignition Key*
11	*Engine Block*	12	*NGV Storage Cylinder*
13	*Wire Connection block*	14	*Battery*
15	*Radiator Fan*	16	*Refuelling Receptacle*
17	*Pressure Sensor*	18	*Pressure Display Unit*
	Petrol Line		*CNG High Pressure Tubing*
	N.G. Low Pressure Tubing		*Ground*
	Typical Common Wire		*High Current Wire*
*	All the other coloured wires belong to the NGV fuel system wiring		

Figure 6 Bi-fuel Engine Rig Set Up

2.0 METHODOLOGY

The engine rpm was gauged using an infrared tachometer installed at the flywheel. The engine rpm was varied by manipulating the throttle opening at the carburettor. The engine rpm was held at a constant value while the fuel consumption and the fuel emission were carried out. The petrol consumption was measured by combining a measuring cylinder and a stopwatch that provided the rate of fuel volume consumed by the engine at a constant engine rpm. The corresponding exhaust emission of the engine was also acquired simultaneously at the same engine rpm. Figure 7.0 indicates sequence of activities for obtaining results of testing. Several runs were conducted for each engine rpm to ensure the repeatability of the result obtained. The engine rpm was increased by 1000 from 1000 to 5000, in order to obtain the fuel consumption and emission behaviour of the bi-fuel engine.

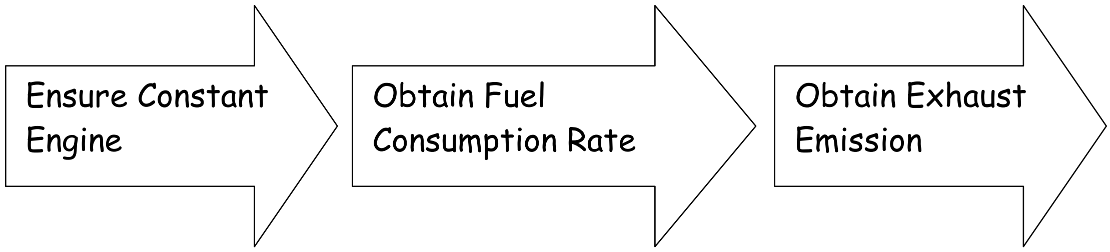


Figure 7 Methodology arranged in sequence for each engine rpm

Similar test was conducted to obtain the natural gas consumption and emission generated at different engine rpm. The method used to measure the natural gas consumption is based on the fact that the storage cylinder pressure will deplete proportionally to the moles of gas consumed at constant engine rpm. Higher engine rpm would consume more fuel, causing greater rate of pressure depletion within the storage cylinder. The relation between the storage pressure and the mol content of gas within the tank is established using suitable thermodynamic equation incorporating the compressibility factor. The time taken for the pressure drop will be used to calculate the mol flowrate of gas consumed. The fuel consumption and corresponding emission result for both petrol and natural gas are displayed in the following section.

3.0 RESULTS & DISCUSSION

3.1 Fuel Consumption Result

The emission results from this bi-fuel test rig operating on natural gas were compared with the results obtained by the Tractors Malaysia that carried out tests based on a similar engine fitted with a Tartarini NGV conversion kit. The unburned hydrocarbon values of 50-60 ppm discharged at 2500 rpm by the Tartarini fuel system (shown in the Appendix B) is similar to the results obtain using the fuel system understudy (Figure 11.0).

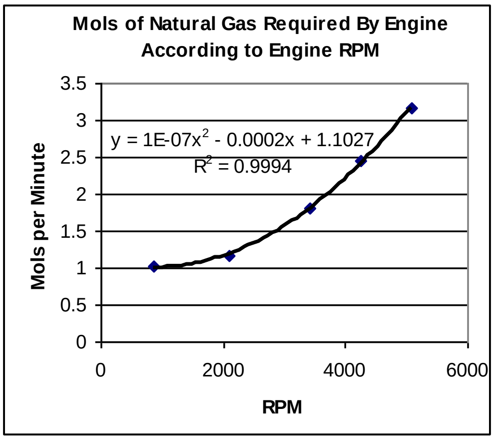


Figure 8 Moles of Natural Gas Required By Engine According to Engine rpm

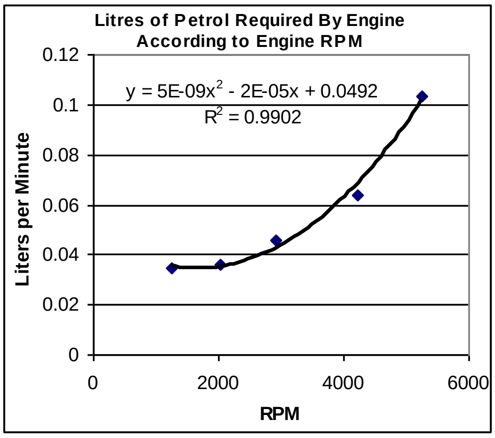


Figure 9 Litres of Petrol Required By Engine According to Engine rpm

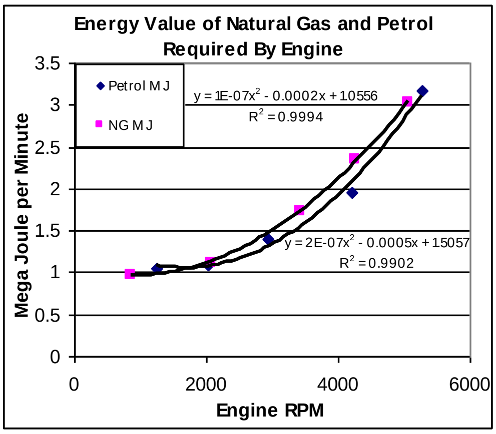


Figure 10 Energy Value of Natural Gas and Petrol Required By Engine

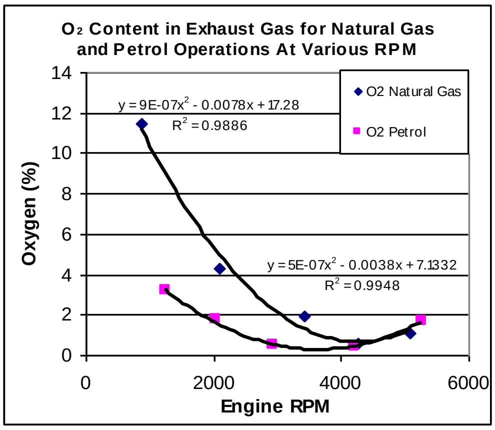


Figure 11 Oxygen Content in Exhaust Gas for Natural Gas and Petrol Operations at Various rpm

The rig understudy releases 0.1 % CO (Figure 12.0) which is much lower then the results from the tartarini fuel system that releases 0.3-0.5% CO (Appendix B). This might had been contributed by the installation of spark advancer in the landi renzo kit understudy but not applied in the tartarini system. This comparison between two types of NGV fuel system authorised to be installed in similar 1500 cc 12 valve engine taxis proves the validity of the result of the study.

The natural gas and petrol consumption at the corresponding engine crankshaft revolutions (rpm) are displayed in Figures 8 and 9, respectively. Both the graphs display similar pattern indicating the engines intrinsic fuel requirement to generate the desired engine rpm. Since the fuel is in different phases, comparisons are done by converting the fuel in terms of energy content (similarly done in Appendix A) as shown in Figure 10.0. The average engine energy requirement is obtained between the natural gas energy supply and the petrol energy supply to the engine. This average value may come in handy with future works on alternative fuel system design.

The percentage of oxygen content of the exhaust gas is obtained using the emission analyser and plotted in Figure 11. The exhaust oxygen content graph displays the lowest oxygen content within the region of 3500 engine rpm for the natural gas operation and 4200 engine rpm for the petrol operation. The most effective combustion occurs within this the minimal oxygen concentrated regions. This effective combustion would cause very low values of unburned hydrocarbon content in the exhaust gas. Figure 13 depicts minimal unburned hydrocarbon values around 3000 rpm for the natural gas operation and 3500 rpm for the petrol operation. This slightly differs from the optimum combustion point described by the exhaust oxygen content in figure. This phenomenon is caused by the intake volumetric efficiency which alters the air to fuel ratio.

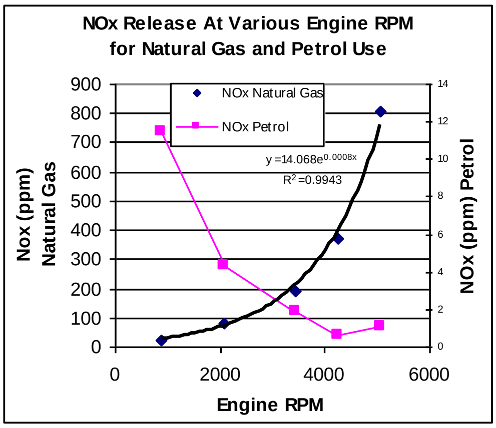


Figure 12 NOx Content in Exhaust Gas at Resulting Engine rpm

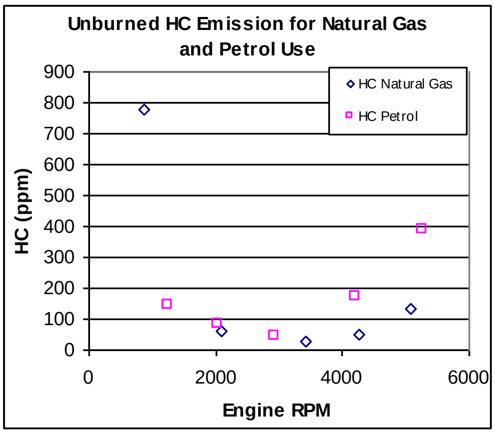


Figure 13 Unburned Hydrocarbon Content in Exhaust Gas at Parallel Engine rpm

The formation of nitrogen oxides are caused either by the combustion itself or the heat of combustion called thermal NOx. Figure 12.0 shows that the formation of NOx during petrol operation decreases with engine rpm. This proves that the NOx is formed due to the poor combustion and mixing factors. As the engine rpm increases, it produced better combustion and mixing causes the NOx formation to decrease. The situation is inversed in the natural gas operation. This occurrence is caused by the formation of thermal NOx, as the operation with natural gas would cause higher exhaust temperature. This temperature increases with the engine rpm as the rate of combustion and exhaust air emission increases.

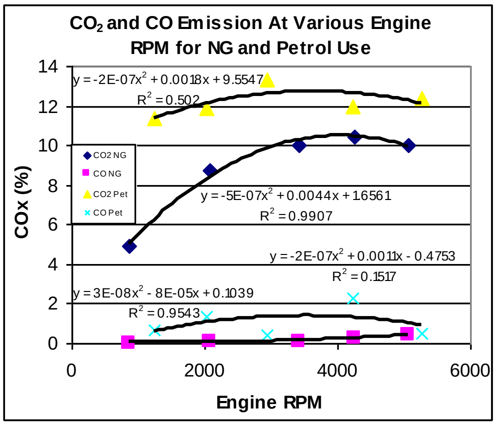


Figure 14 CO_2 and CO Content in Exhaust Gas at Relevant Engine rpm

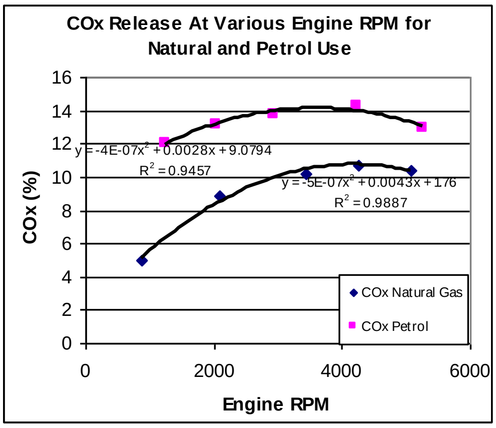


Figure 15 COx Content in Exhaust Gas at Releted Engine rpm

Carbon based emission gases are unavoidable due to the use of carbon based fuels. The formation of carbon monoxide is less favourable compared to carbon dioxide due to its impact on human health. Figure 15 portrays that the use of natural gas as fuel decreases the total carbon based emission gas compared with the petrol operation. The break down of the carbon based exhaust emission is shown in Figure 14 as carbon monoxide and carbon dioxide. Carbon monoxide released by petrol operation is much greater compared to the use of natural gas. The discharge of carbon dioxide is also greater with the use of petrol compared to natural gas.

4.0 CONCLUSION

The results obtained from the bi-fuel test rig have achieved the objective i.e. to provide a comprehensive understanding of the existing bi-fuel system in Malaysia. The emission data obtained has clearly proven that the use of natural gas is much more favourable compared to the use of petrol. The fuel cost calculations has proven that natural gas is not only cleaner burning fuel but also cheaper than the existing mainstream fuels. The most effective combustion occurs at 3500 engine rpm during the operation with natural gas and at 4200 engine rpm for the operation with petrol.

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APPENDIX A

a) From the ideal gas law we know one mole of gas would occupy the following volume at room temperature.

$$v = \frac{RT}{P} = \frac{8.314\,\frac{kPa\cdot Liter}{mol\cdot K}\times 298\,K}{101325\,Pa} = 24.45\,Litres$$

b) Energy content of Natural Gas

$$1053\,\frac{btu}{cft}\times\frac{1\cdot cft}{28.31684659\cdot Litre}\times\frac{24.4\cdot litre(at298K)}{1\cdot mol}\times\frac{1\cdot MJ}{947.8169879\cdot btu} = 0.9573\cdot\frac{MJ}{mol}$$

c) Energy content of 1 Litre of petrol (estimate 1)

$$\frac{0.69\cdot kg}{1\cdot Litre}\times\frac{1000\cdot g}{1\cdot kg}\times\frac{1\cdot mol}{114.23\cdot g}\times\frac{5.07\times 10^{6}\,J}{1\cdot mol}\times\frac{1\cdot MJ}{1\times 10^{6}\,J} = \frac{30.625\cdot MJ}{1\cdot Litre}$$

d) Energy content of 1 Litre of petrol (estimate 2)

$$1\cdot Litre\times\frac{1\cdot mol}{0.165\cdot Litre}\times\frac{5.07\times 10^{6}}{1\cdot mol}\times\frac{1\cdot MJ}{1\times 10^{6}} = \frac{30.727\cdot MJ}{1\cdot mol}$$

e) Energy within a 55 Litre NGV cylinder charged for RM 8.43 based on RM 0.68 NGV = RM 2.70 Petrol Litre Equivalent = 30.676 MJ

$$\frac{RM\,8.43}{cylinder}\times\frac{30.625\cdot MJ}{RM\,0.68} = \frac{379.660\cdot MJ}{cylinder}$$

f) Mol content within a cylinder based on energy per mol of natural gas.

$$\frac{379.660\cdot MJ}{cylinder}\times\frac{1\cdot mol}{0.9573\cdot MJ} = \frac{396.65\cdot mol}{cylinder}$$

APPENDIX B

Emission Reference Chart

Gasoline	HC rpm	CO%
Non-Catalyst : Idle	300	2.5-3.0
Catalyst : Idle	30-100	0.2-0.5
Non-catalyst @2,500 rpm No Load	100	0.5-1.5
Catalyst @2,500 rpm No Load	20-30	0.5-1.5
Non-Catalyst Full Load*	50-70	0.5-1.5
Catalyst Full Load*	10-20	0.1-0.2

Natural Gas	HC rpm	CO%
Non-Catalyst : Idle	100-150	0.5-1.0
Catalyst : Idle	20-50	0.1-0.3
Non-catalyst @2500 rpm No Load	50-60	0.3-0.5
Catalyst @2500 rpm No Load	20-30	0.1-0.3
Non-catalyst: Full Load*	10-20	0.1-0.2
Catalyst Full Load*	10-20	0.1-0.2

*full throttle @ 80 KMH on Dynometer:

2nd gear Automatic	3 or 4 speed
2nd gear Manual	3 speed
3rd gear Manual	4 or 5 speed.

Note : The above chart is for reference purpose only.