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CONVERSION METHOD OF A DIESEL ENGINE TO A CNG-DIESEL DUAL FUEL ENGINE AND ITS FINANCIAL SAVINGS

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ABSTRACT

This paper presents the equipments necessary and methodology to convert a common-rail diesel engine to operate in dual fuel mode using compressed natural gas (CNG) as main fuel. A small quantity of diesel pilot fuel act as an ignition source to initiate the combustion. The conversion system was developed to reduce diesel consumption by manipulating and emulating signal from the common rail pressure sensor without major modification to the engine. The vehicle need to be inspected by several organizations after the conversion process to ensure that the vehicle is safely used on the road by the consumer. This paper is also presents the financial advantages of the conversion a diesel engine to CNG-Diesel dual fuel engine through the Return of Investment (ROI) calculation.

Keywords: dual fuel, conversion method, CNG-Diesel, natural gas vehicle.

INTRODUCTION

Fossil fuels such as petroleum is produced by decomposition of buried dead organisms since over a few million years ago and categorized as non-renewable energy. Petroleum is widely used as an energy resources in generating internal combustion engines. Due to the insufficient supply and expected running out by the next few years, the alternative fuels must to be find in replacing petroleum fuel.

The use of CNG in the automotive application is widely used for spark ignition (SI) engine because of availibilty, inexpensive and less polution. In using CNG as a fuel for compression ignition (CI) engine, a pilot fuel is required as a source of ignition. Since CNG has a low cetane number, a minimum quantity of diesel is injected into combustion chamber to ignite the combustion (Munde and Dalu, 2012).

The biodiesel program in Malaysia has been implemented since 2011 by introducing B5 which contains a blend of 5% palm methyl esters with 95% of diesel. Effective on November 2014, the biofuels mandate in Malaysia is increased from B5 to B7 and officially implemented on 14 January 2015. In the study of Wirawan (Wirawan *et al*., 2008), the emission of hydrocarbon (HC), carbon monoxide (CO) and particulate matter (PM) are decrease when the percentage of biodiesel blend is increase. In study of emission at 50% load condition, the HC and CO emission for all biodiesel blending is less than diesel at variant engine speed (Amir *et al*., 2013). Therefore, the combination of CNG and biodiesel in dual fuel system is the best way to reduce exhaust emission on CI engine (Ryu, 2013)(Shenghua, 2003) and being more economical (Harshavardhann, 2014).

In using dual fuel system on conventional diesel vehicle, there are some limitation involves such as engine geometri and fuel delivery system. Through this project, the dual fuel conversion kit is designed to allow the conventional diesel vehicle using this dual fuel system without any major modification. The vehicle is able to switch between two fuel system operation either diesel single fuel or CNG-diesel dual fuel.

Table-1 shows the specification of vehicle that was used in this project.

Table-1. Vehicle specification.

Vehicle:	Toyota Hilux 2.5 (G)
Displacement:	2,494 cc
Fuel type:	Diesel
Fuel system:	Direct injection with common rail
Number of cylinder:	4 in-line
Compression ratio:	17.4 : 1

DUAL FUEL CONVERSION

Dual fuel kit component

This project used two CNG cylinders Type-2 with 65 litre and 77 litre capacity. The material of these cylinders were made by metalic container and wrapped by fiber glass which is 25% lighter than Type-1. These cylinders must be able to accommodate pressure up to 3600 psi and meet the standard requirement of American National Standards Institute for Natural Gas Vehicle (ANSI NGV 2-2007), Federal Motor Vehicle and Safety Standards (FMVSS 304) or ISO 11439:2000. In Malaysia, each of the CNG cylinders must be included with an approval letter by Department of Occupational Safety and Health (DOSH) to ensure the cylinder is safely used.

The pressure regulator from Tomasetto Achille is used to reduce and regulating CNG pressure before delivered to CNG injector. This pressure regulator is equipped by lock-off valve for safety requirement and controlled by electric current through a solenoid. This pressure regulator is approved by Standards and Industrial Research Institute of Malaysia (SIRIM).

CNG injector is an actuator component that inject CNG into intake manifold and is controlled by electric

current through a solenoid. Two injectors are suffice for this project, depending on the engine size and the number of cylinder.

Hose and piping used for CNG must meet the International Standards Organization (ISO) requirements to avoid the leakage due to chemical reaction. The high pressure steel pipe with PVC coated must to meet requirements of ISO15500 while the rubber hose for this system is made to accommodate high pressure gases according to the standards regulation of United Nations Economic Commission for Europe (UNECE) R110 and R67-01.

MAP sensor is a device that measuring absolute pressure inside intake manifold and then measuring the quantity of air that entering the engine cylinder. This is additional component for the engine which does not have the stock MAP sensor.

This dual fuel system operation is controlled by a special ECU for dual fuel and combining with the stock ECU. This device will collect signal from the sensors and deliver signal to actuator components. The ECU receive signal from accelerator pedal position sensor, crankshaft position sensor and MAP sensor to inject both fuels at the appropriate quantity, pressure and time.

Dual fuel kit installation

The installation diagram of dual duel kit system is shown in Figure-1.
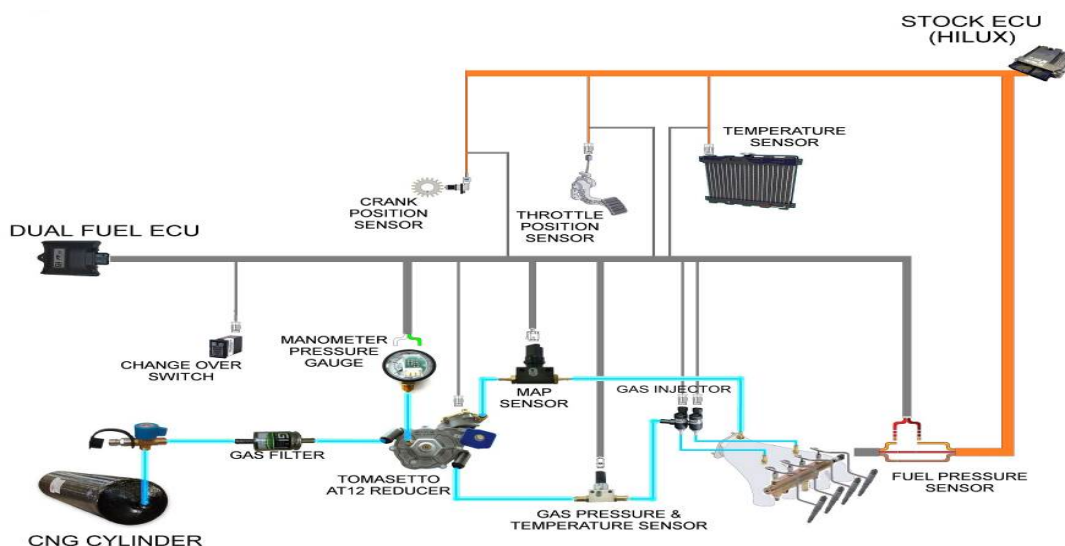
Figure-1. Installation diagram of dual fuel conversion kit.

The CNG cylinders were mounted under the vehicle in the spare tyre location as shown in Figure-2.

Figure-2. CNG cylinders.

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The cylinder bracket was built by iron plate with 10 mm thickness and iron hollow bar with 3 mm thickness. The methods used for joining the elements are using Metal Inert Gas (MIG) welding and bolt. For safety

purpose, bolts and nuts shall used grade 8.8 which are bear up can hold to 800 N/mm2 tensile strength. The clamp is wrapped using rubber mat to avoid damage on the cylinder surface due to vibration and friction as shown in Figure-3.


Figure-3. Rubber mat is attached between clamp and cylinder.

The filling valve is mounted inside the engine compartment where is the common location of installation as shown in Figure-4.

Figure-4. Filling valve installation.

The gas filter is installed before entering the pressure regulator and a manometer pressure gauge is installed on pressure regulator to monitoring pressure level inside the CNG cylinders as shown in Figure-5.
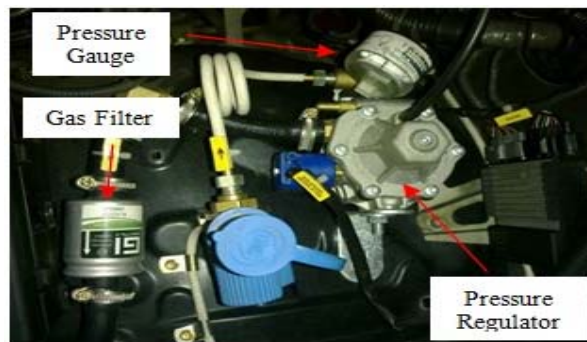
Figure-5. The connection of filter, pressure regulator and pressure gauge.

The MAP sensor is installed between vacum outlet of pressure regulator and intake manifold for measuring the absolute air pressure inside intake manifold and then measuring the quantity of air that entering the engine cylinder. The signal from the MAP sensor is transmitted to the dual fuel ECU and then calculating air-fuel ratio to inject CNG as much as required for combustion as shown in Figure-6.
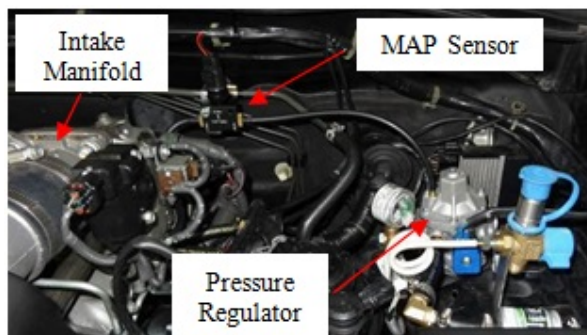

Figure-6. MAP sensor connection between intake manifold and pressure regulator.

The gas pressure and temperature sensor is installed between outlet connection of pressure regulator and the gas injector to measure the pressure and temperature of CNG.

According to the paper of (Eshank *et al*., 2013), the injection method of CNG is an effective method to reduce emissions of unburned hydrocarbons and nitrogen oxides compare to induction method. Thefore, the gas injectors are placed at the intake manifold and close to the inlet valve. All of these components are connected to the dual fuel ECU.

In this conversion, the dual fuel ECU is combined with the stock ECU which are crankshaft position sensor, accelerator pedal position sensor and temperature sensor of the vehicle are parallely connected to the dual fuel ECU and stock ECU.

To reduce the quantity of diesel as a pilot fuel, the dual fuel ECU emulating signal from fuel pressure sensor before delivered to the stock ECU as a Figure-7.
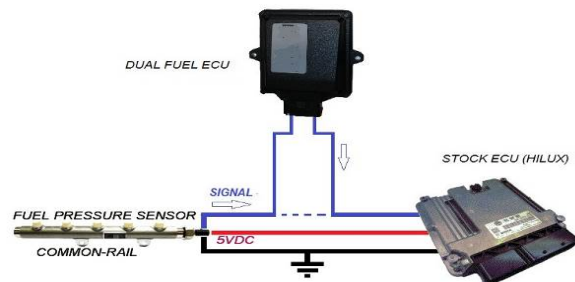
Figure-7. Fuel pressure sensor connection.

The emulated signal raising up the fuel pressure reading in common rail and the stock ECU controlling the fuel pump to decrease the emulated fuel pressure being equal to the normal pressure. As a result, the actual fuel pressure is lower than the normal fuel pressure as shown in Figure-8.
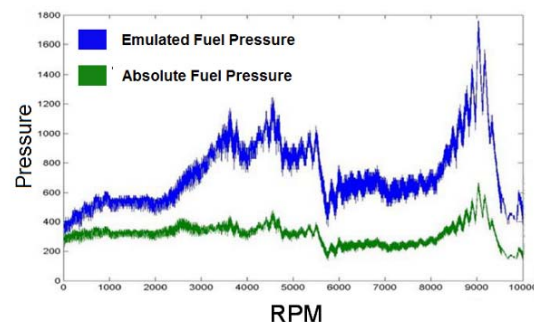
Figure-8. Graph of emulate and absolute fuel pressure.

As a result, the diesel quantity is lowered and substituded by CNG fuel while maintaining the specific air to fuel ratio at a given operating condition.

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CNG fueling

The refueling can be done at any CNG petrol station. The filling process is performed by connecting the fill-up nozzle to the filling valve where is placed inside the engine compartment of vehicle and the process will stop automatically when the cylinder pressure reach about 3300 psi.

Because of the differences between density of liquid and gas, the capacity of CNG that can be loaded into 142 water litre of cylinder is about 31.421 litre at 3300 psi. The theoretical volume of CNG can be calculated using this Boyle's Law equation:

$$P_1V_1 = P_2V_2 \tag{1}$$

P_1 = internal pressure.
V_1 = the cylinder capacity.
P_2 = 1 atm as equal to 14.6 psi.
V_2 = the volume of CNG.

$$3,300\ (142) = 14.696\ V_2 \tag{2}$$

$$V_2 = 31,886.228 \text{ litre} \tag{3}$$

Since the density of water is 999.97 kg/m^3,

$$V_2 = \underline{31,886.228}$$

$$997.97 \text{ gram/litre} \tag{4}$$

$$V_2 = 31.887 \text{ litre} \tag{5}$$

During this project is performed, the subsidized market price of CNG is about RM 0.68 per litre and the total price of this fueling is about RM 21.37 for 31.421 litre of CNG as shown in Figure-9.

Figure-9. The total price of CNG.

Dual fuel conversion kit tuning

Before using this dual fuel mode, the system need to be activated by connecting the dual fuel ECU to the computer. This connection is using Universal Interface Bus (USB) cable and the system was activated using a software. Once the system is activated, the indicator lamp on change-over switch is turned on immediately as shown in Figure-10.
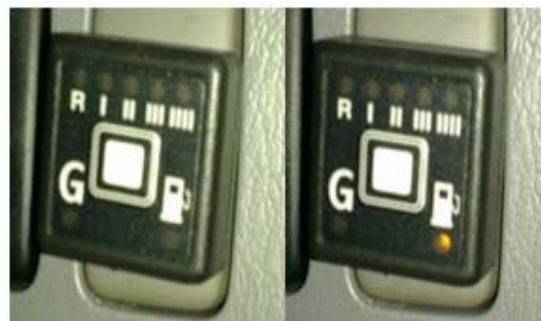

Figure-10. The indicator on change-over switch.

The same software is used to setup this dual fuel system. Before tuning the system, several components shall be calibrated such as accelerator pedal position, fuel pressure sensor and tachometer signal. After the calibration process is done, the system is tuned by mapping the dual fuel ECU as shown in Figure-11.
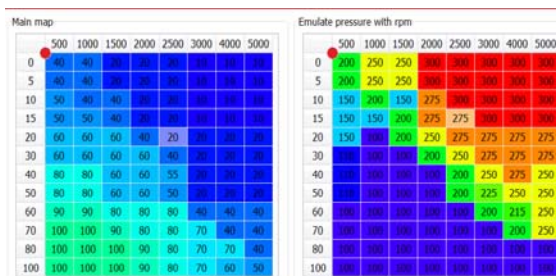

Figure-11. Dual fuel mapping.

This map is used to control the ratio of CNG and diesel at the certain load condition. The low load is the condition where the engine speed is high but the throttle opening is low while the high load is the condition where the engine speed is low but the throttle opening is high.

Basically, the quantity of CNG is more than the diesel for this dual fuel system. At the high load condition, the quantity of diesel is increased to give more power to the engine. Using this map, the quantity of CNG is controlled by main map and the quantity of diesel is controlled by emulate fuel pressure map.

COMMISIONING

Inspection by an authorized installer

The installation of natural gas system for vehicle need to be inspected by qualified inspector who was certified by *Majlis Latihan Vokasional Kebangsaan Malaysia* (MLVK). The inspection is focused on leak testing, component fitting and certificate of components.

Inspection by Pusat pemeriksaan kenderaan berkomputer (PUSPAKOM)

As an on-road vehicle in Malaysia, this vehicle must to be inspected by PUSPAKOM due to the fuel conversion. The processes involved for this inspection are

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component fitting, emission testing, component certificates and MLVK certificate of the installer. The special inspection report (*Laporan* B2) is issued by PUSPAKOM after the inspection is done.

Endorsement by jabatan pengangkutan jalan Malaysia (JPJ)

The endorsement of the fuel conversion was issued by JPJ and all of the documents are checked including component certificates, MLVK certificate of the installer, JPJ certificate of the installer, certificate of installation and *Laporan* B2. In this project, the vehicle is pass for endorsement and eligible for 62% reduction of road tax.

RETURN OF INVESTMENT (ROI)

The ROI for this installation is calculated by several assumption. This dual fuel system is using 60% of CNG and 40% of diesel and the installation cost is about RM 9,000.00.

The dual fuel price is the total price of 60% CNG and 40% diesel per litre.

$$\$_{DF} = 60\% \text{ CNG} + 40\% \text{ Diesel} \tag{6}$$

$\$_{DF}$ = dual fuel price.

The fuel cost consumption is calculated by mutiplying the fuel consumption of vehicle and fuel price per litre. Normally, the unit of fuel consumption is L/100km.

$$Cost_D = FC \times \$_{Diesel} \tag{7}$$

$$Cost_{DF} = FC \times \$_{DF} \tag{8}$$

$$Cost_{SAVE} = Cost_D - Cost_{DF} \tag{9}$$

$Cost_D$ = diesel cost.
$Cost_{DF}$ = dual fuel cost.
$Cost_{SAVE}$ = saving cost
FC = fuel consumption.
$\$_{Diesel}$ = diesel price.

The saving cost per annum is calculated by multiplying the saving cost per km and average travel distance per year.

$$Saving/year = Cost_{SAVE} \times \delta_{ANNUAL} \tag{10}$$

δ_{ANNUAL} = average travel distance per year

The ROI of the installation is calculated by dividing installation cost to saving cost per annum.

$$ROI = \frac{Installation\ Cost}{Saving/year} \tag{11}$$

During this paper was written, the subsidized diesel price in Malaysia is RM 2.20/liter and the subsidized CNG price is RM 0.68/liter. Based on these equations, the ROI table is calculated as in Table-2. This ROI calculation does not include the saving gain from road tax reduction of approximately RM 500/year for 2.5 liter diesel engine.

Table-2. Return of investment for installation.

	Fuel Consumption (L/100km)	Diesel Fuel Cost (RM/100 km)	Dual Fuel Cost (RM/100 km)	Based on travelling about 25,000				Based on travelling about 50,000				Based on travelling about 75,000			
				Diesel Cost per Year (RM)	Dual Fuel Cost per Year (RM)	Saving Cost per Year (RM)	Period of ROI (years)	Diesel Cost per Year (RM)	Dual Fuel Cost per Year (RM)	Saving Cost per Year (RM)	Period of ROI (years)	Diesel Cost per Year (RM)	Dual Fuel Cost per Year (RM)	Saving Cost per Year (RM)	Period of ROI (years)
GOOD	7.5	16.50	9.66	4125.00	2415.00	1710.00	5.3	8250.00	4830.00	3420.00	2.6	12375.00	7245.00	5130.00	1.8
	7.9	17.38	10.18	4345.00	2543.80	1801.20	5.0	8690.00	5087.60	3602.40	2.5	13035.00	7631.40	5403.60	1.7
NORMAL	8.0	17.60	10.30	4400.00	2576.00	1824.00	4.9	8800.00	5152.00	3648.00	2.5	13200.00	7728.00	5472.00	1.6
	8.5	18.70	10.95	4675.00	2737.00	1938.00	4.6	9350.00	5474.00	3876.00	2.3	14025.00	8211.00	5814.00	1.5
	8.9	19.58	11.46	4895.00	2865.80	2029.20	4.4	9790.00	5731.60	4058.40	2.2	14685.00	8597.40	6087.60	1.5
	9.0	19.80	11.59	4950.00	2898.00	2052.00	4.4	9900.00	5796.00	4104.00	2.2	14850.00	8694.00	6156.00	1.5
	9.5	20.90	12.24	5225.00	3059.00	2166.00	4.2	10450.00	6118.00	4332.00	2.1	15675.00	9177.00	6498.00	1.4
	9.9	21.78	12.75	5445.00	3187.80	2257.20	4.0	10890.00	6375.60	4514.40	2.0	16335.00	9563.40	6771.60	1.3
	10.0	22.00	12.88	5500.00	3220.00	2280.00	3.9	11000.00	6440.00	4560.00	2.0	16500.00	9660.00	6840.00	1.3
	10.5	23.10	13.52	5775.00	3381.00	2394.00	3.8	11550.00	6762.00	4788.00	1.9	17325.00	10143.00	7182.00	1.3
	10.9	23.98	14.04	5995.00	3509.80	2485.20	3.6	11990.00	7019.60	4970.40	1.8	17985.00	10529.40	7455.60	1.2
POOR	11.0	24.20	14.17	6050.00	3542.00	2508.00	3.6	12100.00	7084.00	5016.00	1.8	18150.00	10626.00	7524.00	1.2
	11.5	25.30	14.81	6325.00	3703.00	2622.00	3.4	12650.00	7406.00	5244.00	1.7	18975.00	11109.00	7866.00	1.1

According to Table-2, the fuel consumption and average travel distance per year are influencing the period of ROI. The shortest period of ROI is achieved by the

vehicle which has high travelling distance per year and high of fuel consumption. The longest period of ROI is the

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vehicle which has low travelling distance per year and low fuel consumption.

CONCLUSIONS

The CNG-Diesel dual fuel conversion kit with 142 litre CNG tanks Type 2 was successfully installed on the diesel vehicle without any major modification on chasis and engine. This conversion was recognized by several organization such as authorized NGV installer, PUSPAKOM and JPJ. Based on the ROI calculation, the installation of the dual fuel conversion kit is highly recommended to a vehicle that has high fuel consumption and large travelling distance to meet the shortest period of ROI.

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REFERENCES

[1] Munde Gopal, G., Dalu Rajendra, S. (2012). Compressed Natural Gas as an Alternative Fuel for Spark Ignition Engine: A Review International Journal of Engineering and Innovative Technology, 2(6), pp.92--96

[2] Wirawan, S.S, Tambunan, A.H., Djamin, M. and Nabetani, H. (2008). The Effect of Palm Biodiesel Fuel on the Performance and Emission of the Automotive Diesel Engine. Agricultural Engineering International: the CIGR Ejournal. Manuscript EE 07 005.

[3] Amir, K., Shahrul, A.O., Md Norrizam, M.J., Norrizal, M., Siti Mariam, B. and Manshoor, B. (2013). Performance and Emissions Characteristics of Diesel Engine Fuelled by Biodiesel Derived from Palm Oil. Applied Mechanics and Materials, 315, pp.517--522

[4] Kyunghyun Ryu (2013). Effect of Pilot Injection Pressure on the Combustion and Emission Characteristics in a Diesel Engine using Biodiesel-CNG Dual Fuel. ELSEVIER Ltd, Energy Conservation and Management, 76, pp.506--516.

[5] Shenghua, L., Longbao, Z., Ziyan, W. and Jiang, R. (2003). Combustion Characteristics Of Compressed Natural Gas/Diesel Dual-Fuel Turbocharged Compressed Ignition Engine. Proceedings of the Institution of Mechanical Engineers, 217(9), pp.833--838

[6] Harshavardhann, D. (2014). Performance and Emission Characteristics of Rice Bran Biodiesel in Dual Fuel Mode with CNG in Single Cylinder Four Stroke Diesel Engine.

[7] International Conference on Recent Trends in Engineering and Technology.

[8] Eshank.D.Doijode, Prajwal.Tewari, Y.H.Basavarajappa, N.R.Banapurmath, V.S. Yaliwal (2013). Experimental Studies on Manifold Injected CNG-Biodiesel Dual Fuel Engine. International Journal of Emerging Technology and Advanced Engineering, 3(3), pp.77—83.