Performance and Emissions of 1.3L and 1.6L Engines Fueled with Gasoline and CNG at Several Vehicle Speeds

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Abstract

The main objective of this work was to investigate a comparison between engine performance and exhaust emissions for 1.3L and 1.6L 4-cylinder engines fueled with gasoline or compressed natural gas (CNG). The test engines were fitted with the same CNG conversion kit, which operated with either gasoline or CNG. The engine performance and exhaust emissions were measured over vehicle speeds at 30 km/h, 50 km/h, 70 km/h, 90 km/h, and 100 km/h, with half throttle valve position. The results showed that brake powers decreased at an average of 25.18% and 33.94% when using CNG fuel. There is also a reduction in brake specific energy consumptions at an average of 17.25% for 1.3L engines. However, there is an increment of brake specific energy consumption at a lower speed for 1.6L engine fueled with CNG. The 1.3L engine produces higher exhaust gas temperatures at an average of 5.14% when running on CNG. The exhaust emissions of the 1.6L engine fueled with CNG showed higher HC, CO, O_2, NO_x and lower CO_2 compared to the 1.3L engine fueled with the same fuel.

1. Introduction

Concern on air pollution has grown over the years and had caused a negative effect on humans. One of the culprits contributed in this situation is emissions from automotive vehicles running on conventional fuels [1]. Studies on alternative fuels that could substitute this conventional fuel, which has similar performance with lower emissions, became potential candidates to be used in the coming years [2] and [3]. It is expected that an alternative fuel substitute which emits less air pollutant and more economical compared to conventional fuels could address the issue on the uncontrolled vehicle emissions [4][5]. Even though the current trend in the transportation sector is favoring electric vehicles, the lack of resources and infrastructures lead to utilization of alternative fuel [6]. There are many potential alternative fuels being research, such as bio-diesel, bio-alcohol, natural gas, and biogas [7]. Due to the abundance of natural gas, compressed natural gas (CNG) has become a favorable candidate for alternative fuel [1]. CNG also has lower emissions rates, low prices and suitable for gasoline engines as well as the conventional diesel engine. As a result, CNG is much accepted for vehicle fuel in recent years [8].

Many studies had proven that CNG fuels produced lower emissions rate compared to other conventional fuels. A study by [9] and [10] on the spark-ignition engine running on CNG produced lower HC, CO, and O_2 emissions compared to gasoline fuel. Another study by [3] on the effect of CNG injection pressure on performance, emissions and combustion characteristics of multi-cylinder spark ignition (SI) engine showing lower HC, CO and oxides compared to gasoline fuel. However, there is a significant increase in NO_x emissions compared to gasoline fuel [11]. The CNG fuel brake power is significantly lower than gasoline fuel. As reported by [9], the brake power was decreased between 10.86 % and 19.25 % at 50 % and 80% throttle position for variable engine speed range. It is expected since CNG has a lower flame speed compared to gasoline. The CNG fuel has been widely accepted due to its lower emissions with an ability to adapt to the current existing engines [12]. Commonly, these vehicles required to install retrofitted kits to enable the usage of CNG as fuel [9]. Similar to the experiment that had been conducted by [9] on the comparative engine performance and emissions analysis of gasoline and CNG, the testing required an incorporated bi-fuel system to test the CNG fuel. However, in this experimental study, an experiment was conducted to compare engine performance and emissions for 1.3L and 1.6L spark-ignition engines when they were retrofitted with the same CNG kit.

2. MATERIAL AND METHOD

2.1 Experimental Setup

The experiments were conducted using a 1.3L and 1.6L 4-cylinder spark-ignition engine to evaluate the performance and emissions of gasoline and CNG fuel (1.3L gasoline (GAS-1.3), 1.3L CNG (CNG-1.3), 1.6L gasoline (GAS-1.6), 1.6L CNG (CNG-1.6)). The 1.3L and 1.6L 4-cylinder spark-ignition represent B-Segment and C-Segment engine size, respectively which is the target for Natural Gas Vehicle (NGV) consumer. The

specification of test engines is shown in Table 1. The engine was retrofitted with CNG kit AEBMP48 to enable CNG injection into the engine because of its tuneable hardware to suit different spark-ignition engines. The kit capable of converting the engine to run on bi-fuel mode, which is either petrol or CNG. Besides, the kit also equipped with Tomasetto Achille At12 pressure regulator, 4 unit 12V gas sequential injectors and three portable 210 liter CNG cylinder for sufficient CNG supply to the engine for AEB MP48 calibration and experiment.

Table 1. Test engine specification (Gasoline)

Engine Type	K3-VEI4 (1.3L)	CamPro S4PH (1.6L)
Engine Displacement, cc	1298	1597
Number of cylinders	4	4
Compression ratio	10:1	10.1
Bore, mm	72	76
Stroke, mm	79.7	88
Max. power, kW/rpm	67/6000	82/6000
Max. torque, N.m/rpm	116/3200	148/4000

The engine performance test was conducted by hooking the wheel on chassis dynamometer Dynapack 4022. The engine fuel system was connected to liquid fuel mass flow meter (Ono Sokki FZ-2100) for gasoline flowrate measurement. Also, the gas flow meter was connected (Alicat M250SLPM) for measuring gas fuel consumption. An OBD-II ECU diagnostic (Bosch KTS-570) was connected to the engine ECU for real-time engine behavior monitoring. A type-K thermocouple was tapped at the exhaust manifold to obtained the exhaust gas temperatures and was logged using PicoLogger. The exhaust emissions were measured using SPTC Autocheck 5 Channel Gas emissions analyzer. The schematic diagram of the experimental setup is shown in Figure 1.
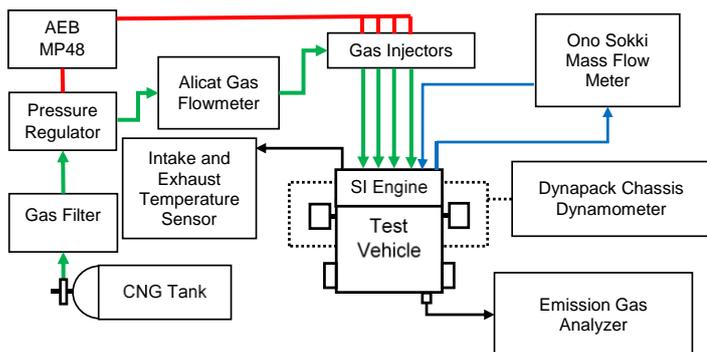
Figure 1. Schematic diagram of the experimental setup

2.2 Experimental Parameter

The experiments were carried out in steady-state conditions at constant vehicle speed range from 30 km/h, 50 km/h, 70 km/h, 90 km/h, and 110 km/h. The vehicle speeds were chosen to represent various speed range for rural, urban, suburban, and highway. The experiments were conducted at 50% throttle valve position (TVP) for medium load driving at particular vehicle speed. The gear ratio for both engines was set at 1:1 ratio at 4th gear allowing direct output from the engine to the drive shaft. The fuel used in the testing are gasoline RON95 and CNG fuel. The gasoline was acquired from local Petron station and CNG was acquired from local Petronas station. The physical and chemical properties of gasoline are presented in Table 2, while the volumetric composition of CNG, physical and chemical properties of CNG are presented in Table 3 and Table 4, respectively.

Gasoline was used as a baseline fuel for the comparative study.

Table 2. Physical and chemical properties of gasoline [13]

Properties	Descriptions
Density at 15°C, kg/L	0.7519
Research octane number (RON)	95
Color, visual	Yellow
Copper corrosion, 3 hrs. at 50°C	1
Distillation, °C	
Initial boiling point	32
10% Recovery	53
50% Recovery	89
90% Recovery	144
Final boiling point	179
Dry vapor pressure equivalent at 37.8°C, kPa	61.7
Sulphur, mg/kg	3
Benzene, Vol%	2.5

Table 3. Volumetric composition of CNG [9]

Component	Symbol	Volumetric %
Methane	CH_4	94.42
Ethane	C_2H_6	2.29
Propane	C_3H_8	0.03
Butane	C_4H_{10}	0.25
Carbon dioxide	CO_2	0.57
Nitrogen	N_2	0.44
Others	$(H_2O +)$	2.00

Table 4. Physical and chemical properties of CNG [14]

Properties	Descriptions
Appearance	Colorless gas
Odor	Pungent odor – Mercaptan mixture (added)
Boiling point	-162 °C
Vapor density at 760 mm Hg	0.747 kg/Sm^3
Specific gravity at 760 mm Hg	0.61
Flashpoint	-187 °C
Autoignition temperature	537 °C

3. RESULT AND DISCUSSION

3.1 Brake Power (BP)

Figure 2 shows the graph of brake power against vehicle speed for 1.3L and 1.6L engines fueled by gasoline and CNG and percentage difference for gasoline – CNG and CNG – CNG between two engine sizes. From Figure 2 (a), the results show increment in brake power when the vehicle speeds were increased. The 1.6L engine has higher brake power compared to the 1.3L engine due to different displacement. Figure 2 also shows the CNG fuel result for both vehicles has lower brake power compared to gasoline fuel. The percentage difference between gasoline and CNG for 1.3L and 1.6L engine are 18.59% - 34.61% and 15.85% - 48.67% respectively. From the graph, it can be observed that CNG-1.6 has lower brake power at 50 km/h and 70 km/h compared to CNG-1.6 and GAS-1.3 due to misfire occurrence. According to [15], CamPro S4PH 1.6L is having low-end torque dip problems caused by the geometry of the designed intake manifold and valve timing. These problems lead to a phenomenon named Compression Misfire due to the loss of compression in the cylinder. However, this misfire occurrence is only for this 1.6L engine and would not affect other 1.6L engines. The difference in power is bigger than stated in the literature, which approximately 15% to 20% difference [3]. From the graph, at CNG-1.3 and CNG-1.6 has similar brake power up to 70 km/h, the brake power for CNG-1.6 started to increase at 90 km/h to 110 km/h with a percentage difference of 38.08% and 42.06% respectively. The test was conducted using a commercial engine with factory stock ECU, and it was expected that the difference is obvious because of a different manufacturer.
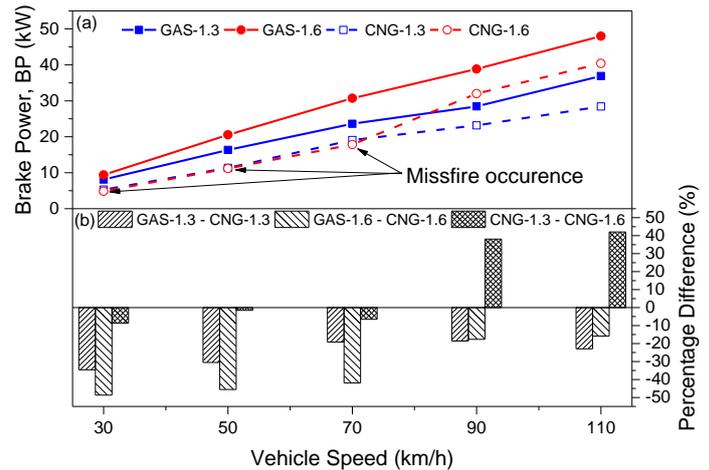

Figure 2. (a) Brake Power for 1.3L and 1.6L fueled with gasoline and CNG (b) Percentage difference for gasoline – CNG and CNG – CNG between two engine sizes

3.2 Brake Specific Energy Consumption (BSEC)

Brake specific fuel consumption (BSEC) has been used to estimate the fuel economy of the test engine with different fuel because of the difference between the lower heating value of test fuel (44 MJ/kg and 50 MJ/kg for gasoline and CNG respectively). BSEC is calculated and presented in Figure 3 (a). From the figure, the BSEC graph shows a similar trend except for the CNG-1.6. The result on CNG-1.6 produces the highest BSEC from vehicle speed 30km/h to 70km/h, and the trend changes at 90km/h to 110km/h where the results have lower BSEC compared to other results. The CNG-1.3 has lower BSEC compared to gasoline throughout the experiment with percentage difference varied from 5.99% - 30.30%. Meanwhile, the CNG-1.6 has higher BSEC than GAS-1.6 from 30 km/h to 70 km/h but lower BSEC at 90 km/h and 110 km/h with the overall percentage difference between 7.34% to 63.93%. Besides, the CNG fuel has lower flame speed and a higher octane number required changing the ignition timing to increase the combustion performance, as previously mentioned by [16] which in this case not change. Lower combustion performance had increased the fuel

consumption at low vehicle speed and increased the BSEC on the CNG-1.6. Frequent misfire during low vehicle speed for CNG-1.6 also being observed indicating incorrect engine ignition timing for CNG fuel. In this experiment, the 1.3L engine has a higher BSEC compared to the 1.6L engine. The 1.3L engine required more energy to produce the same amount of power as a 1.6L engine due to its lower displacement which produces less power.
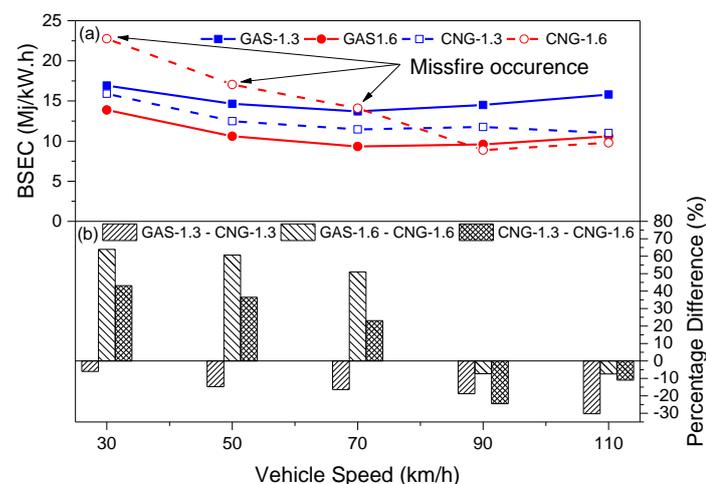

Figure 3. (a) Brake Specific Energy Consumption for 1.3L and 1.6L fueled with gasoline and CNG, (b) Percentage difference for gasoline – CNG and CNG – CNG between two engines size

3.3 Exhaust Gas Temperature (EGT)

The comparison of exhaust gas temperature (EGT) for both 1.3L and 1.6L test engine running on gasoline and CNG are shown in Figure 4 (a). The results show an increment of EGT as the vehicle speed is increased due to a higher rate of combustion. Also, the heat remained trapped at high engine speed, causing the heat transfer between water jacket and coolant to take a longer time to achieve thermal equilibrium at higher rpm. However, EGT for GAS-1.3 at 110 km/h has a lower temperature compared to 90 km/h. There is misfire during low vehicle speed causing the quality of the combustion to be reduced and has lower EGT. During misfire occurrence, the energy

consumption will increase to compensate for the power losses. However, the power output will not increase further as the ECU has fixed the ignition timing. The occurrence of this misfire also can be observed from the hydrocarbon result as a frequent misfire at low vehicle speed for CNG-1.6 which has high HC value. Also, the GAS-1.3 has higher HC value compared to CNG-1.3 due to high unburnt fuel from the misfire. The result for GAS-1.3 is also showing lower EGT at 30 km/h and 50 km/h due to misfire. The result on HC also showing a similar occurrence in which GAS-1.3 has higher HC compare to CNG-1.3 at 30 km/h and 50 km/h, respectively.
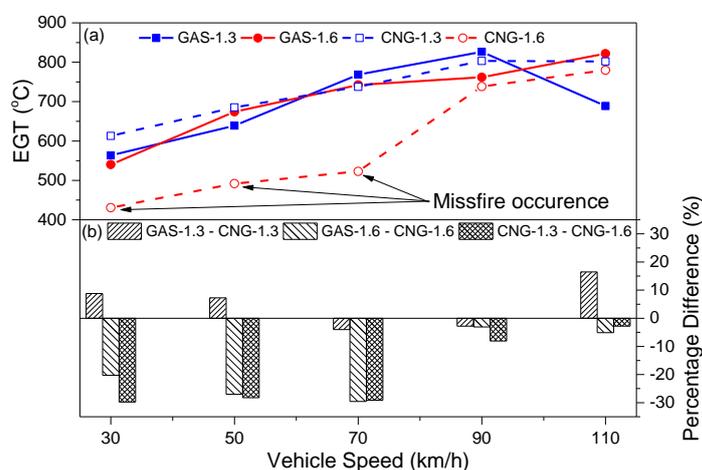

Figure 4. (a) Exhaust gas temperature for 1.3L and 1.6L engine fueled with gasoline and CNG, (b) Percentage difference for gasoline – CNG and CNG – CNG between two engine sizes

3.4 Hydrocarbon (HC)

The amount of HC release is related to engine behavior, commonly is due to poor combustion caused by rich air-fuel mixture and misfire. Figure 5 shows HC for both the 1.3L and 16L engines run on gasoline and CNG. The bar chart in Figure 5 shows that the CNG-1.3 run on CNG produced lower HC compared to GAS-1.3 which runs on gasoline. High HC for GAS-1.3 at 30, 50, and 110 km/h was due to misfire, as mention in the EGT section. The HC result for the 1.6L engine shows that CNG fuel produced higher unburnt fuel

compared to gasoline. At 30km/h, 50km/h and 70km/h, the HC produced is unusually high compared to other vehicle speed range. The misfiring occurs highly due to the stock engine control unit (ECU) factory setting. Since the mapping of CNG ECU is calibrated based on stock ECU, the result is also affected.
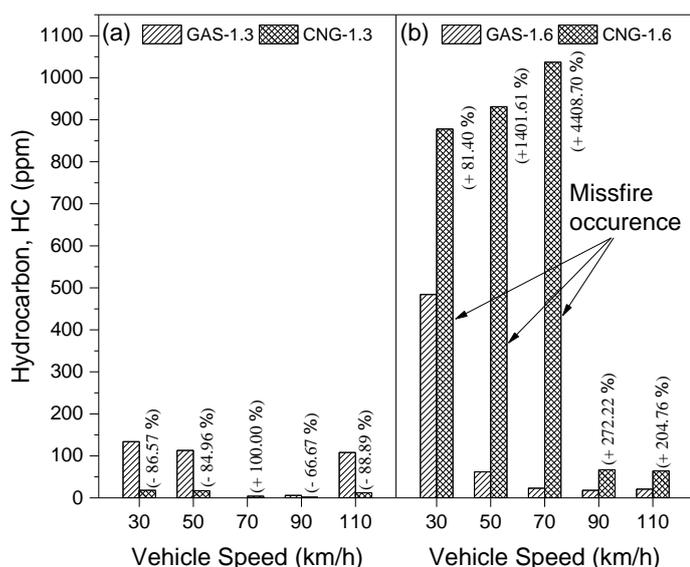

Figure 5. Hydrocarbon (HC) emissions for gasoline and CNG (a) 1.3L (b) 1.6L

3.5 Carbon Monoxide (CO)

Carbon monoxide (CO) concentration is associated with different fuel and air mixtures during combustion. A rich mixture produces more CO emissions in exhaust gases after combustion. Low CO emissions were indicating the air-fuel mixture close to the stoichiometric point [16]. According to [9] the formation of CO emissions is due to poor mixing of air and fuel, local rich regions and incomplete combustion. Figure 6 shows the CO emissions for 1.3L and 1.6L for both gasoline and CNG at a variable vehicle speed range from 30 km/h to 110 km/h. Based on the graph, CNG produces lower CO emissions compared to gasoline, especially for 1.3L. However, the result for 1.6L had slightly higher CO emissions for CNG-1.6 at 50km/h and 70 km/h with an increment of 19.35 % and 50.00 %, respectively.
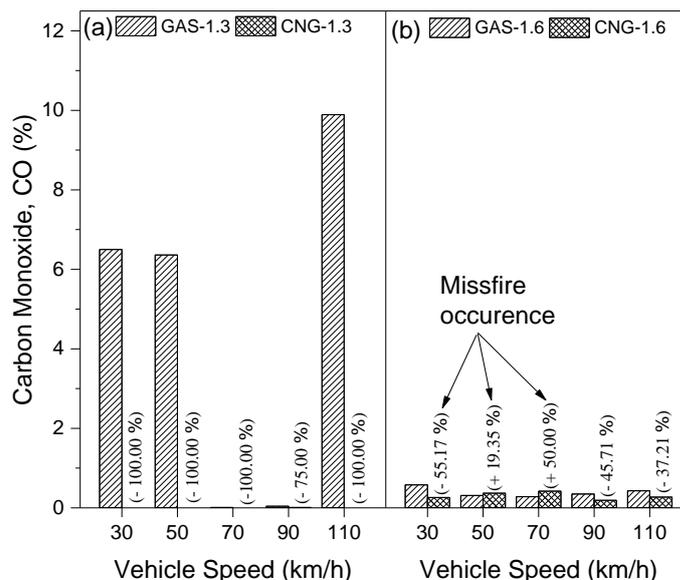

Figure 6. Carbon monoxide emissions for gasoline and CNG (a) 1.3L (b) 1.6L

3.6 Carbon Dioxide (CO_2)

The carbon dioxide (CO_2) produced is an indication of the complete combustion of fuel [17]. Also, this supports the higher value of EGT. Figure 7 shows CO_2 emissions for 1.3L and 1.6L engine run on gasoline and CNG, respectively. The graph shows a similar trend to the EGT results, where at high temperatures, the CO_2 emissions increase accordingly. The lowest CO_2 emissions for GAS-1.3 is at 70 km/h, while the lowest is at 110 km/h with a value of 8.45% and 14.71%, respectively. The CO_2 emissions for CNG-1.3 showing higher value compared to GAS-1.3 except at 70 km/h and 90 km/h ranged from 10.45% to 11.23%. The percentage difference between GAS-1.3 and CNG-1.3 is ranged from 0.85% to 23.94%. The GAS-1.6 CO_2 emissions have close value ranged from 13.01% to 14.05%. Throughout the experiment, CO_2 emissions for CNG-1.6 has lower CO_2 emissions compared to GAS-1.6 with 6.96% at 30 km/h being the lowest while 10.73% at 110 km/h for the highest. The percentage difference between GAS-1.6 and CNG-1.6 ranged from 46.50% to 43.56%. As for CNG-1.3 and CNG-1.6 CO_2 emissions, CNG-1.6 has lower value compare to CNG-1.3.
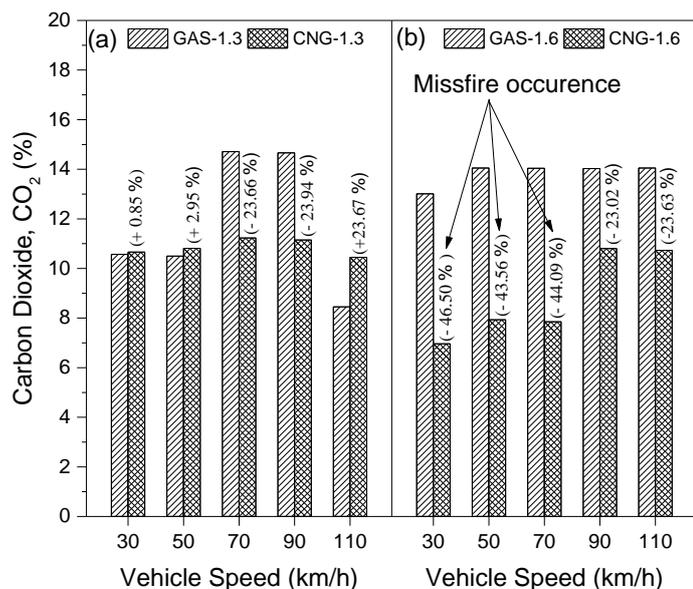
Figure 7. Carbon dioxide (CO_2) emissions for gasoline and CNG (a) 1.3L (b) 1.6L

Figure 8. Oxygen (O_2) emissions for gasoline and CNG (a) 1.3L (b) 1.6L

3.7 Oxygen (O_2)

Figure 8 shows O_2 emissions for 1.3L and 1.6L engine fueled with gasoline and CNG at various vehicle speed range. From the graph, it can be observed that the O_2 has a higher concentration at low vehicle speed and decreased at higher vehicle speed for both engine setup. The O_2 concentration decreased at higher vehicle speed is due to complete combustion with engine speed increases. The CNG-1.3 has lower O_2 concentration at a lower vehicle speed compared to CNG-1.6. However, the CNG-1.6 produced very high O_2 emissions at lower vehicle speeds because of misfire occurrence. The same phenomenon can be seen at HC results caused by a high excess of air and fuel during combustion.
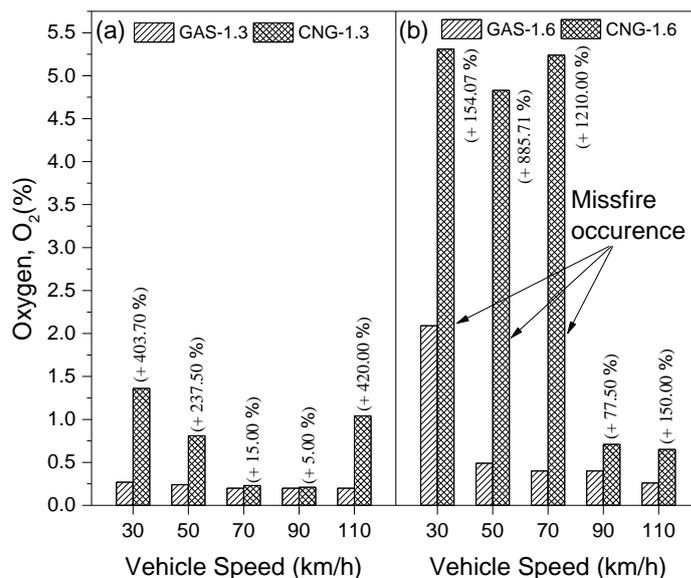
3.8 Nitrogen Oxide (NO_x)

The comparison of NO_x formation between 1.3L and 1.6L fueled with gasoline and CNG is shown in Figure 9. The GAS-1.3 has low NO_x concentration because of a good air-fuel mixture. However, the CNG-1.3 produced a higher NO_x concentration with the lowest is 52 ppm at 90 km/h and the highest is 1812 ppm at 110 km/h. The higher concentration of NO_x is due to lean fuel and high cylinder temperature. In contrast, the 1.6L engine has an increasing NO_x concentration trend for both gasoline and CNG, indicating lean fuel and high cylinder temperature throughout the vehicle speed range. The lowest NO_x for the CNG-1.6 is 307 ppm at 30km/h, while the highest is at 90km/h with 1479 ppm. Although CNG-1.6 had misfire during combustion at low vehicle speeds, it has better NO_x concentration compared to 1.3L because of its lower value to the baseline.
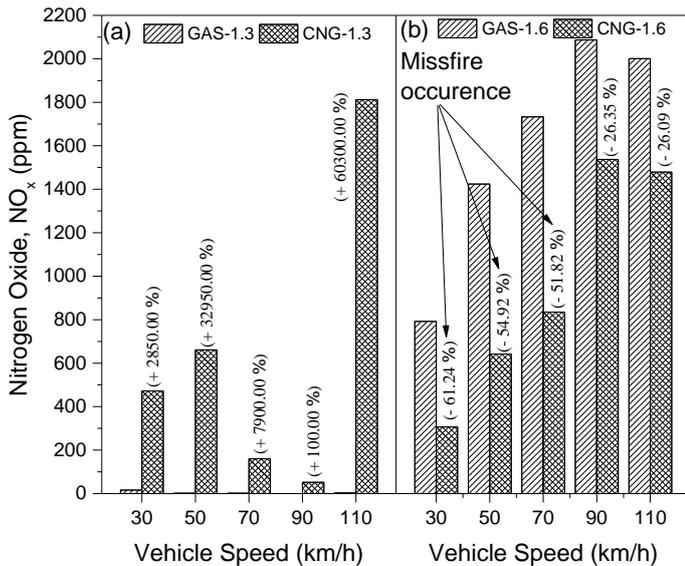
Figure 9. Nitrogen Oxide (NO_x) emissions for gasoline and CNG (a) 1.3L (b) 1.6L

4. CONCLUSION

Experiments have been conducted on 1.3L and 1.6L engines fueled with gasoline and CNG with the same retrofitted CNG kit. The following conclusion can be drawn on the effect of using the same CNG kit on two different engines fueled with CNG.

i. The CNG kit has successfully run on both 1.3L and 1.6L engines. The engines require different settings in the CNG kit for both 1.3L and 1.6L engines to run properly. Different engine size requires different mapping as the amount of air and fuel entering the combustion chamber is not the same.

ii. The brake power produced for both CNG-1.3 and CNG-1.6 decreased with an average of 25.18% and 33.94%, respectively. The CNG-1.6 shows a lower brake power at 30 km/h to 70 km/h, which is almost similar to the brake power of CNG-1.3 due to misfire occurrence.

iii. On the other hand, the BSEC of CNG-1.6 has a higher value at 30 km/h to 70 km/h compared to CNG-1.3, also due to the misfire occurrence. However, the overall

results show the CNG fuel BSEC has lower value compared to gasoline, indicating lower fuel consumption.

iv. The effect of misfire during combustion also caused the EGT of CNG1.6 to have a lower value compared to CNG-1.3. The CNG-1.3 has better combustion compared to CNG-1.6 while using this CNG kit.

v. The HC emissions for CNG-1.3 and CNG-1.6 are higher compared to GAS-1.3 and GAS-1.6, respectively. The CO emissions for CNG-1.3 and CNG-1.6 showed lower values compared to the gasoline result for both engines.

vi. The CNG-1.3 shows higher CO_2 emissions at 30, 50, and 110 km/h but lower CO_2 emissions at 70 km/h and 90 km/h compared to GAS-1.3. Meanwhile, CNG-1.6 shows lower CO_2 emissions compared to GAS-1.3 throughout the experiments. The O_2 and NOx emissions for CNG-1.3 show higher value compared to GAS-1.3. However, CNG 1.6 has more elevated O_2 but lower NO_x compared to GAS-1.6.

5. ACKNOWLEDGEMENT

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