



## **Comparison of CO<sub>2</sub> Emissions from Vehicles in Thailand**

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### **Abstract**

Emission of carbon dioxide (CO<sub>2</sub>), a greenhouse gas, from typical passenger vehicles in Thailand was investigated using a chassis dynamometer in the Automotive Emission Laboratory. The vehicle running method was controlled under the standard Bangkok driving cycle. CO<sub>2</sub> emissions were measured at three different speeds for the following four vehicle types commonly used in Thailand: heavy duty diesel (HDD), light duty diesel (LDD), and light duty gasoline (LDG) vehicles and motorcycles (MC). HDD vehicles had the highest average CO<sub>2</sub> emission rate, followed by LDD, LDG and MC at 1,198.8±93.1, 268.4±21.3, 166.1±27.7 and 42.5±6.1 g km<sup>-1</sup>, respectively; all values were significantly different ( $p < 0.05$ ) from each other. The effect of different fuel types, including diesel, gasoline 91, gasohol 95, gasohol 91, liquid petroleum gas (LPG) and natural gas for vehicles (NGV), on the CO<sub>2</sub> emission level was also compared. HDD vehicles had a higher rate of CO<sub>2</sub> emission when using either NGV or diesel, while LDD vehicles emitted more CO<sub>2</sub> with diesel than with NGV. For LDG vehicles, more CO<sub>2</sub> was emitted with gasohol 91 than with gasohol E20, LPG or NGV. Finally, MC had a higher average CO<sub>2</sub> emission rate with gasohol 95 than with gasoline 91 and gasohol 91 at any vehicle speed. The CO<sub>2</sub> emission rates obtained in this study can be used as a basis to create a database that supports development of an efficient transportation management system and reduced vehicular emission of greenhouse gases in Thailand.

**Keywords:** Emission; Greenhouse gas; CO<sub>2</sub>; Vehicle type; Fuel type; Driving speed

## Introduction

Carbon dioxide (CO<sub>2</sub>) is recognized as a greenhouse gas (GHG), and the transport sector is the second largest emitter of anthropogenic CO<sub>2</sub> worldwide. The gas is mostly generated as a by-product of fuel combustion in transport vehicles [1]. Over recent years, CO<sub>2</sub> emissions from typical passenger vehicles have grown at the highest rate ever recorded, especially in many metropolitan and urban areas around the world [2]. Moreover, the annual rate of CO<sub>2</sub> emission tends to increase substantially as a result of urban expansion [3]. The increased CO<sub>2</sub> emitted from typical passenger vehicles is directly connected to the high fuel combustion rate [4] and is a significant contributor to increased emission of GHGs [5]. In Thailand, the transportation sector has a high rate of fuel consumption, with about 75.7 % used for road transport [6]. The various types of fuel typically used for passenger vehicles in Thailand include petroleum-based diesel and gasoline and the alternative fuels of gasohol, liquefied petroleum gas (LPG) and natural gas for vehicles (NGV). Gasohol, a mixture of gasoline and locally-produced ethanol, helps to reduce consumption of gasoline and the country's reliance on crude oil imports. The high fuel consumption for transportation purposes results in a high levels of CO<sub>2</sub> emissions in the exhaust gas [7]. The rate of CO<sub>2</sub> emitted by vehicles can be calculated from the relationship between vehicle speed, total concentration of CO<sub>2</sub> detected in the exhaust gas and total distance travelled [8]. Key factors affecting CO<sub>2</sub> emission, such as vehicle type, fuel type and driving cycle, have recently been tested [9]. However, there have been very few studies in Thailand in relation to the effect of speed on emissions. For this reason, this study set out to investigate CO<sub>2</sub> emission levels from various types of passenger vehicles used in Thailand at different speeds, using speed-time data collected on routes in the study area, and distance data

under a Bangkok driving cycle. The results from this study can be used to create a database for the development of a more efficient transportation management system to further reduce vehicular GHG emissions in Thailand.

## Material and methods

### 1) Experimental design

In this study, vehicles were classified into four types, which included (i) heavy duty diesel (HDD), (ii) light duty diesel (LDD), (iii) light duty gasoline (LDG) and (iv) motorcycles (MC), as defined elsewhere [10]. Vehicle types and ages (see Table 1) were some of the in-used vehicle types in Thailand. Various factors affecting CO<sub>2</sub> emissions were identified and studied in the Automotive Emission Laboratory (AEL) of the Pollution Control Department, Ministry of Natural Resources and Environment. In addition, the different categories of fuel commonly used in Thailand, such as diesel, gasoline 91, gasohol 95, gasohol 91, gasohol E20, LPG and NGV, were compared in this study to analyze the effects of different fuel types on the CO<sub>2</sub> emission level for each vehicle type.

### 2) CO<sub>2</sub> emission testing and analysis

The CO<sub>2</sub> emission analysis of all vehicles in this study was conducted in the AEL, which is fully equipped to perform emissions and performance testing. All vehicle tests were performed under the same conditions, while temperature and humidity were controlled to simulate real-world road driving conditions. At the beginning of the analysis, each vehicle was tested using a chassis dynamometer, comprising a single roller and cooling fan, to simulate road-driving conditions. Vehicle test conditions were performed under a Bangkok driving cycle [10]. Moreover, vehicle tests were performed under hot soak at the three speed ranges of 0-20, 20-40 and 40-80 km h<sup>-1</sup>. Exhaust gas sampling was conducted by direct sampler measurement and constant volume sampler

systems. The AEL collected and sampled exhaust gases including dilution air for measuring the concentration of CO<sub>2</sub>. The concentration of CO<sub>2</sub> was subsequently measured together with the (i) exhaust flow rate, (ii) air dilution process, (iii) constant sampling and accumulation of exhaust gas and (iv) measurement of the total volume of diluted exhaust. After these measurements, the exhaust sample was transferred to a model 7200FM

GFC analyzer, fitted with a CO<sub>2</sub> detector, and then analyzed by non-dispersive infrared analyzer (NDIR), which shines an infrared beam through a sample cell containing CO<sub>2</sub> and measures the amount of infrared absorbed by the sample at the necessary wavelength. The NDIR detector is used to measure the volumetric concentration of CO<sub>2</sub> in the sample. The fuel consumption rate was then calculated.

**Table 1** Background information obtained from the AEL for the four types of in-use vehicles used in this study

| Vehicle type | Engine capacity (cc)          | Engine standard (year) | Fuel type   | Sample number |
|--------------|-------------------------------|------------------------|-------------|---------------|
| HDD          | Bus<br>(8,500 cc)             | EURO II<br>(2001)      | Diesel      | 5             |
|              |                               |                        | NGV         | 5             |
| LDD          | Pick up and Van<br>(2,500 cc) | EURO III<br>(2005)     | Diesel      | 5             |
|              |                               |                        | NGV         | 5             |
| LDG          | Passenger car<br>(2,000 cc)   | EURO III<br>(2005)     | Gasohol 91  | 5             |
|              |                               |                        | Gasohol E20 | 5             |
|              |                               |                        | LPG         | 5             |
|              |                               |                        | NGV         | 5             |
| MC           | Motorcycle<br>(125 cc)        | EURO III<br>(2005)     | Gasoline 91 | 5             |
|              |                               |                        | Gasohol 95  | 5             |
|              |                               |                        | Gasohol 91  | 5             |

### 3) CO<sub>2</sub> emission calculation

The CO<sub>2</sub> emission rate was calculated using the relationship between CO<sub>2</sub> concentration in the exhaust gas and the distance of vehicle running at different speeds was calculated using speed-time [11]. The significance of any differences between the means was analyzed using analysis of variance (ANOVA) statistical models at the 95 % confidence level. The data variances were compared with those of the means using Duncan's New Multiple Range Test (DMRT). The CO<sub>2</sub> emission calculation is illustrated in the following equation.

$$\text{CO}_2 \text{ Emission (g km}^{-1}\text{)} = \frac{\text{Concentration of CO}_2\text{(g)}}{\text{Distance (km)}}$$

where the emission of CO<sub>2</sub> is the total rate of CO<sub>2</sub> emission, the concentration of CO<sub>2</sub> is

the total concentration of CO<sub>2</sub> detected in the exhaust gas, and the distance is the total distance of vehicle travel.

## Results and discussions

### 1) CO<sub>2</sub> emission from diesel engine vehicles

Table 2 and Figure 1 present the CO<sub>2</sub> emission levels measured from two types of diesel engine vehicles (8,500 cc HDD and 2,500 cc LDD), with different types of fuel, tested using a chassis dynamometer.

#### 1.1) CO<sub>2</sub> emission rates from HDD

For the HDD with diesel, the CO<sub>2</sub> emission rate was 1,036.4-1,212.9 g km<sup>-1</sup> with no significant difference but different vehicle speeds between diesel and NGV were significantly different at 20-40 and 40-80 km h<sup>-1</sup>. This result is in accord with the results of previous studies

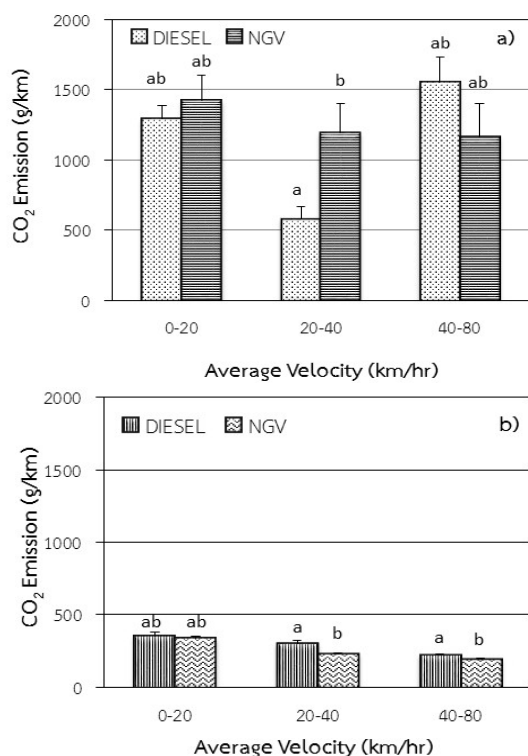
[12-13], which reported that, compared to the proportion of O<sub>2</sub> and N<sub>2</sub> in the fuel, 50 % of the diesel emissions were CO<sub>2</sub>. The average CO<sub>2</sub> emission level was dependent on vehicle speed, as demonstrated by the following results: 1,290.6 ±96.7, 577.3±91.6 and 1,568.4±179.1 g km<sup>-1</sup> at 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively. Thus, CO<sub>2</sub> emissions were minimal at 20-40 km h<sup>-1</sup> and markedly higher at slower and faster speeds (2.2- and 2.7-fold, respectively). This result might

be due to the high net weight of the HDDV resulting in a high fuel combustion rate at the initial stage of vehicle movement, and decreasing when the transmission gear was lowered to reduce the weight burden. The combustion rate then increased again at faster speeds to overcome increasing wind resistance. Fontaras et al. [14] also studied the GHGs emitted from HDD in Europe and found a 24 % higher GHG emission from HDD compared to other sources of GHGs emission.

**Table 2** CO<sub>2</sub> emission from diesel engine (HDD and LDD) vehicles with different types of fuel

| Vehicle type/fuel                | Mileage of engine | CO <sub>2</sub> emission (g km <sup>-1</sup> ) and speed range (km h <sup>-1</sup> ) |                            |                            | Average CO <sub>2</sub> emission in 1 driving cycle (g km <sup>-1</sup> ) |
|----------------------------------|-------------------|--|----------------------------|----------------------------|---|
|                                  |                   | 0-20 km h <sup>-1</sup>  | 20-40 km h <sup>-1</sup>   | 40-80 km h <sup>-1</sup>   |   |
| HDD (diesel)                     |                   |  |                            |                            |   |
| 1                                | 53,255            | 1,185.8  | 459.2                      | 1,464.3                    | 1,036.4   |
| 2                                | 668,763           | 1,323.2  | 587.8                      | 1,727.7                    | 1,212.9   |
| 3                                | 613,424           | 1,452.0  | 737.2                      | 1,251.1                    | 1,146.8   |
| 4                                | 712,028           | 1,197.7  | 529.2                      | 1,585.3                    | 1,104.1   |
| 5                                | 726,395           | 1,294.2  | 572.9                      | 1,725.8                    | 1,197.6   |
| Average CO <sub>2</sub> emission |                   | 1,290.6±96.7 <sup>a</sup>  | 577.3±91.6 <sup>a</sup>    | 1,550.9±179.1 <sup>a</sup> | 1,139.6±64.3 <sup>a</sup>   |
| HDD (NGV)                        |                   |  |                            |                            |   |
| 1                                | 1,548             | 1,151.2  | 822.9                      | 1,568.4                    | 1,180.8   |
| 2                                | 3,282             | 1,359.9  | 1,221.6                    | 1,098.4                    | 1,226.6   |
| 3                                | 4,928             | 1,616.6  | 1,371.3                    | 1,147.8                    | 1,378.6   |
| 4                                | 444,009           | 1,509.3  | 1,279.1                    | 1,022.2                    | 1,270.2   |
| 5                                | 845,540           | 1,475.0  | 1,245.3                    | 981.7                      | 1,234.0   |
| Average CO <sub>2</sub> emission |                   | 1,422.4±177.1 <sup>a</sup>   | 1,188.0±211.9 <sup>b</sup> | 1,163.7±235.3 <sup>b</sup> | 1,258.0±74.5 <sup>b</sup>   |
| LDD (diesel)                     |                   |  |                            |                            |   |
| 1                                | 95,573            | 326.3  | 305.4                      | 215.8                      | 282.5   |
| 2                                | 160,081           | 391.9  | 260.5                      | 219.8                      | 290.7   |
| 3                                | 267,837           | 344.5  | 309.3                      | 219.4                      | 291.1   |
| 4                                | 508,627           | 341.5  | 301.6                      | 210.6                      | 284.6   |
| 5                                | 727,586           | 355.2  | 323.2                      | 228.0                      | 302.1   |
| Average CO <sub>2</sub> emission |                   | 351.9±24.6 <sup>b</sup>  | 300.0±23.5 <sup>c</sup>    | 218.7±6.4 <sup>c</sup>     | 290.2±7.7 <sup>c</sup>  |
| LDD (NGV)                        |                   |  |                            |                            |   |
| 1                                | 112,738           | 348.3  | 232.6                      | 196.8                      | 259.2   |
| 2                                | 120,152           | 350.27   | 244.98                     | 203.1                      | 266.1   |
| 3                                | 225,164           | 326.71   | 218.72                     | 191.91                     | 245.8   |
| 4                                | 254,744           | 320.69   | 221.31                     | 184.58                     | 242.2   |
| 5                                | 342,786           | 323.78   | 217.71                     | 187.7                      | 243.0   |
| Average CO <sub>2</sub> emission |                   | 333.9±14.2 <sup>b</sup>  | 227.1±11.6 <sup>c</sup>    | 192.8±7.4 <sup>c</sup>     | 251.3±10.8 <sup>c</sup>   |

**Note:** Means in a row with a different superscript lowercase letter are significantly different ( $p < 0.05$ , using DMRT test)



**Figure 1** CO<sub>2</sub> emission from (a) HDD and (b) LDD using diesel or NGV fuel at a vehicle speed of 0-20, 20-40 and 40-80 km h<sup>-1</sup>. Data are shown as the mean±1SD, derived from five independent vehicles. Means with a different lowercase letter are significantly different ( $p < 0.05$ ; using DMRT test).

The CO<sub>2</sub> emission of HDD with NGV fuel ranged from 1,180.8 to 1,378.6 g km<sup>-1</sup>, with no significant difference in the CO<sub>2</sub> emission rate with different mileage engines, and only a slight numerical (but not statistically significant) decrease with increasing vehicle speeds (1,422.4±177.1, 1,188.0±211.9 and 1,163.7±74.5 g km<sup>-1</sup> for 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively). However, higher levels of CO<sub>2</sub> were emitted from HDD running on NGV than with diesel at any vehicle speed, which might be due to the lower density of carbon compounds found in the gaseous state of NGV than in the liquid state of diesel fuel. These results also explain why the CO<sub>2</sub> emission from HDD with NGV did not show any significant differences at different vehicle speeds. This observation is congruent with Grigoratos et al.

[15], who reported a significant difference in the CO<sub>2</sub> emission from HDD with diesel and NGV fuel in Italy at a vehicle speed of 20-40 km h<sup>-1</sup> but not at other speeds (Figure 1a).

### 1.2) CO<sub>2</sub> emission rates from LDD

The CO<sub>2</sub> emission rate from LDD with diesel fuel ranged from 282.5 to 302.1 g km<sup>-1</sup>, but the CO<sub>2</sub> emission rate decreased with increasing vehicle speeds (345.5±24.6, 300.0±23.5 and 218.7±6.4 g km<sup>-1</sup> at 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively). This trend might reflect the higher fuel combustion rate at the start of the vehicle, which subsequently decreased with increasing vehicle speed. Therefore, CO<sub>2</sub> emissions were lower at a higher speed. This result is in agreement with Zachroff et al. [16], who studied CO<sub>2</sub> emission of LDD in Europe.

For LDD, NGV produced a lower CO<sub>2</sub> emission rate (242.2-266.1 g km<sup>-1</sup>) than diesel and showed no significant difference with respect to engine mileage. A marked dependence in the CO<sub>2</sub> emission rate on the vehicle speed was noted, which is demonstrated in the following results: 333.9±14.2, 227.1±11.6 and 192.8±7.4 g km<sup>-1</sup> at 0-20, 20-40, and 40-80 km h<sup>-1</sup>, respectively. The same trend was observed for CO<sub>2</sub> emitted from LDD with diesel fuel. These results are in accord with those of Bielaczek et al. [17], who studies CO<sub>2</sub> emission for vehicles using NGV fuel.

With respect to CO<sub>2</sub> emissions from LDD with diesel or NGV fuel, a significant difference ( $p < 0.05$ ) was found at vehicle speeds of 20-40 and 40-80 km h<sup>-1</sup> but not at 0-20 km h<sup>-1</sup> (Figure 1b).

### 2) CO<sub>2</sub> emission rates from gasoline engine vehicles

The CO<sub>2</sub> emission rates from two different sizes of gasoline engine vehicles (2,000 cc. LDG vehicle and 125 cc MC) with different types of fuel, were evaluated by a chassis dynamometer, and the results are summarized in Table 3 to 4 and Figure 2.

### 2.1) CO<sub>2</sub> emission rates from LDG

The CO<sub>2</sub> emission rate from LDG with gasohol 91 ranged from 149.6 to 252.5 g km<sup>-1</sup> with no significant difference with increasing engine mileage. The average CO<sub>2</sub> emission rate tended to decrease with increasing vehicle speed (204.6±43.5, 183.7±43.1 and 174.2±37.1 g km<sup>-1</sup> for 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively). These results might be due to the high fuel combustion rate at the start of the test, where the CO<sub>2</sub> emission rate gradually decreased as the fuel combustion rate decreased at higher vehicle speeds, which was also found with LDD. These results are consistent with those of Wang et al. [18], who found that CO<sub>2</sub> emissions from gasoline engine vehicles were dependent upon the engine was continuously run at a typical city driving speed and decreased with increasing vehicle speeds.

The average CO<sub>2</sub> emission rate from LDG with gasohol E20, LPG and NGV was 120.8-173.9, 158.7-174.9 and 145.6-167.8 g km<sup>-1</sup>, respectively, with no significant difference based on engine mileage. The CO<sub>2</sub> emission rates from LDG with gasohol E20 decreased with increasing vehicle speed (162.4±28.2, 141.8±23.6 and 135.1±20.9 g km<sup>-1</sup> at 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively), which is the same trend as LDG with gasohol 91. With LPG, the CO<sub>2</sub> emission rate was higher than with gasohol E20 and also decreased with increasing vehicle speed (191.8±17.5, 166.8±9.1 and 156.6±5.6 g km<sup>-1</sup> at 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively). Likewise, the CO<sub>2</sub> emission rates with LPG showed the same trend as those with gasohol 91 and gasohol E20 and also with NGV (175.2±13.2, 157.5±11.0 and 144.2±7.5 g km<sup>-1</sup> at 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively).

Thus, LDG using gasohol E20 and NGV as fuel had a lower CO<sub>2</sub> emission rate than with gasohol 91 and LPG. These results are congruent with the study of Choi et al. [19], who found no significant difference in the CO<sub>2</sub>

emission rates of LDGV using either gasohol 91 or NGV at any vehicle speed, and Bielacz et al. [20], who investigated GHGs emissions from LDG.

The chassis dynamometer test in this study confirmed a significant difference ( $p < 0.05$ ) in the CO<sub>2</sub> emission rates of LDG vehicles using gasohol E20 or LPG at 0-20 and 20-40 km h<sup>-1</sup> (Figure 2a), congruent with the results of Gupta et al. [21], who evaluated GHGs emissions by LDG using alternative fuels in India.

### 2.2) CO<sub>2</sub> emission rates from MC

The CO<sub>2</sub> emission rates for MC with gasoline 91 ranged from 37.7 to 42.8 g km<sup>-1</sup> with no significant difference in the mileage of the MC engine. The CO<sub>2</sub> emission rate decreased with increasing MC speed (45.1±7.5, 37.4±1.6 and 36.5±3.2 g km<sup>-1</sup> at 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively), again likely to reflect the higher fuel combustion rate at the beginning of test with both the combustion rate and fuel consumption being lower at higher vehicle speeds (the same trend as for LDD and LDG). With gasohol 95, the average CO<sub>2</sub> emission rate was slightly higher (38.1-54.6 g km<sup>-1</sup>) than with gasoline 91 but again showed no dependence on the engine mileage and with a decreased emission rate at higher vehicle speeds (52.0±8.1, 46.3±7.3 and 46.9±6.2 g km<sup>-1</sup> at 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively), displaying a similar trend as that of gasoline 91 (Figure 2b). With gasohol 91, the CO<sub>2</sub> emission rate was slightly lower (35.4-43.2 g km<sup>-1</sup>) than with gasohol 95 or gasoline 91 but again with no dependence on engine mileage but on vehicle speed (42.8±3.0, 37.5±2.9 and 38.3±4.7 g km<sup>-1</sup> for 0-20, 20-40 and 40-80 km h<sup>-1</sup>, respectively).

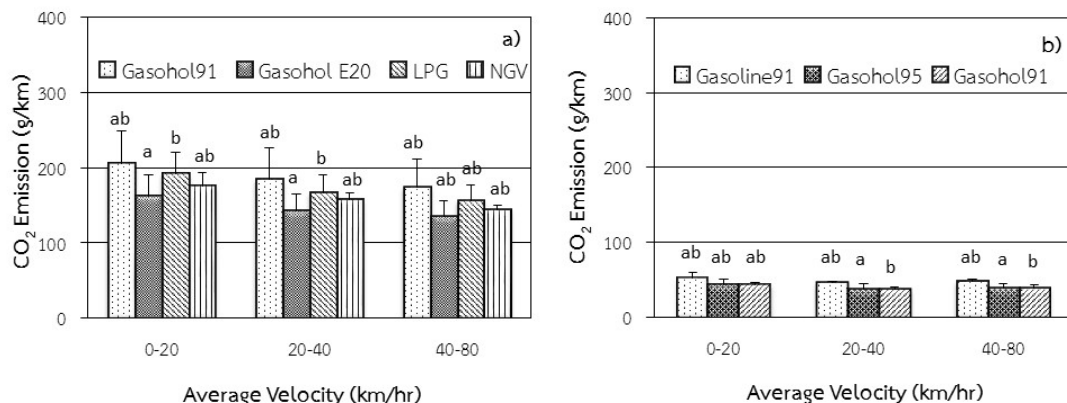
Overall, MC with gasohol 91 had a lower CO<sub>2</sub> emission rate than with gasoline 91 and gasohol 95 at all speed rates and the new MC seem to have higher CO<sub>2</sub> emission than older on because it have new engine technology can be completed burning of fuel, which is in agree-

ment with the results of Costagliola et al. [22]. Although the CO<sub>2</sub> emission rates decreased numerically with increasing vehicle speed with all fuel types, this trend was not significant except for MC with gasohol 95 and gasohol 91

at 20-40 and 40-80 km h<sup>-1</sup>. These results were in accordance with those of Hassani et al. [23], who reported that 40 % of CO<sub>2</sub> and exhausted gas emissions in Tehran (Iran) originated from an MC of 125 cc.

**Table 3** CO<sub>2</sub> emission rates from LDG vehicles with different types of fuel

| Vehicle type/fuel                | Mileage of engine     | CO <sub>2</sub> emission (g km <sup>-1</sup> ) and Speed range (km h <sup>-1</sup> ) |                          |                          | Average CO <sub>2</sub> emission in 1 driving cycle (g km <sup>-1</sup> ) |
|----------------------------------|-----------------------|--|--------------------------|--------------------------|---|
|                                  |                       | 0-20 km h <sup>-1</sup>  | 20-40 km h <sup>-1</sup> | 40-80 km h <sup>-1</sup> |   |
| LDGV (Gasohol 91)                |                       |  |                          |                          |   |
| 1                                | 9,562 <sup>ab</sup>   | 168.2  | 153.0                    | 145.5                    | 155.6   |
| 2                                | 26,608 <sup>ab</sup>  | 214.4  | 191.6                    | 183.7                    | 196.6   |
| 3                                | 88,533 <sup>ab</sup>  | 165.1  | 141.8                    | 141.9                    | 149.6   |
| 4                                | 119,931 <sup>ab</sup> | 202.7  | 180.3                    | 166.7                    | 183.3   |
| 5                                | 200,061 <sup>ab</sup> | 272.4  | 251.9                    | 233.2                    | 252.5   |
| Average CO <sub>2</sub> emission |                       | 204.6±43.5 <sup>a</sup>  | 183.7±43.1 <sup>a</sup>  | 174.2±37.1 <sup>a</sup>  | 187.5±41.2 <sup>a</sup>   |
| LDGV (Gasohol E20)               |                       |  |                          |                          |   |
| 1                                | 147,652 <sup>a</sup>  | 188.7  | 164.9                    | 155.0                    | 169.5   |
| 2                                | 112,944 <sup>a</sup>  | 159.9  | 134.4                    | 125.1                    | 139.8   |
| 3                                | 177,771 <sup>a</sup>  | 140.3  | 124.0                    | 120.1                    | 128.1   |
| 4                                | 172,687 <sup>a</sup>  | 193.0  | 168.4                    | 160.3                    | 173.9   |
| 5                                | 122,359 <sup>a</sup>  | 130.0  | 117.1                    | 115.2                    | 120.8   |
| Average CO <sub>2</sub> emission |                       | 162.4±28.2 <sup>ab</sup>   | 141.8±23.6 <sup>ab</sup> | 135.1±20.9 <sup>ab</sup> | 146.4±24.1 <sup>ab</sup>  |
| LDGV (LPG)                       |                       |  |                          |                          |   |
| 1                                | 81,979 <sup>a</sup>   | 192.3  | 171.1                    | 161.5                    | 174.9   |
| 2                                | 111,596 <sup>a</sup>  | 172.9  | 156.0                    | 147.1                    | 158.7   |
| 3                                | 131,010 <sup>a</sup>  | 183.2  | 159.0                    | 156.4                    | 166.2   |
| 4                                | 174,823 <sup>a</sup>  | 220.0  | 178.1                    | 159.0                    | 185.7   |
| 5                                | 300,993 <sup>a</sup>  | 190.6  | 169.6                    | 159.1                    | 173.1   |
| Average CO <sub>2</sub> emission |                       | 191.8±17.5 <sup>ab</sup>   | 166.8±9.1 <sup>ab</sup>  | 156.6±5.6 <sup>b</sup>   | 171.7±10.1 <sup>b</sup>   |
| LDGV (NGV)                       |                       |  |                          |                          |   |
| 1                                | 119,922 <sup>c</sup>  | 164.9  | 147.4                    | 136.5                    | 149.6   |
| 2                                | 217,860 <sup>c</sup>  | 185.3  | 167.9                    | 150.2                    | 167.8   |
| 3                                | 270,827 <sup>c</sup>  | 183.1  | 163.9                    | 147.7                    | 164.9   |
| 4                                | 275,480 <sup>c</sup>  | 185.3  | 164.2                    | 151.0                    | 166.8   |
| 5                                | 473,774 <sup>c</sup>  | 157.3  | 143.9                    | 135.8                    | 145.6   |
| Average CO <sub>2</sub> emission |                       | 175.2±13.2 <sup>b</sup>  | 157.5±11.0 <sup>c</sup>  | 144.2±7.5 <sup>b</sup>   | 159.0±10.5 <sup>b</sup>   |



**Figure 2** CO<sub>2</sub> emission from (a) LDG and (b) MC vehicles with different fuels and vehicle speeds. Data are shown as the mean  $\pm$  1 SD, derived from five independent vehicles. Means with a different lowercase letter are significantly different ( $p < 0.05$ ; using DMRT test).

**Table 4** CO<sub>2</sub> emission rates from MC vehicles with different types of fuel

| Vehicle type/fuel                | Mileage of engine   | CO <sub>2</sub> emission (g km <sup>-1</sup> ) and Speed range (km h <sup>-1</sup> ) |                          |                          | Average CO <sub>2</sub> emission in 1 driving cycle (g km <sup>-1</sup> ) |
|----------------------------------|---------------------|--|--------------------------|--------------------------|---|
|                                  |                     | 0-20 km h <sup>-1</sup>  | 20-40 km h <sup>-1</sup> | 40-80 km h <sup>-1</sup> |   |
| MC (Gasoline 91)                 |                     |  |                          |                          |   |
| 1                                | 3 <sup>b</sup>      | 41.0   | 36.9                     | 40.3                     | 39.4  |
| 2                                | 183 <sup>b</sup>    | 45.9   | 39.6                     | 35.4                     | 40.3  |
| 3                                | 225 <sup>b</sup>    | 41.9   | 35.7                     | 35.7                     | 37.7  |
| 4                                | 623 <sup>b</sup>    | 39.0   | 36.3                     | 39.1                     | 38.1  |
| 5                                | 3,355 <sup>b</sup>  | 57.7   | 38.5                     | 32.2                     | 42.8  |
| Average CO <sub>2</sub> emission |                     | 45.1±7.5 <sup>c</sup>  | 37.4±1.6 <sup>c</sup>    | 36.5±3.2 <sup>c</sup>    | 39.7±2.0 <sup>c</sup>   |
| MC (Gasoline 95)                 |                     |  |                          |                          |   |
| 1                                | 150 <sup>b</sup>    | 52.3   | 50.1                     | 50.9                     | 51.1  |
| 2                                | 4,967 <sup>b</sup>  | 59.0   | 51.5                     | 51.7                     | 54.1  |
| 3                                | 5,169 <sup>b</sup>  | 60.2   | 52.7                     | 50.7                     | 54.6  |
| 4                                | 5,273 <sup>b</sup>  | 40.6   | 36.4                     | 37.2                     | 38.1  |
| 5                                | 6,688 <sup>b</sup>  | 48.2   | 40.9                     | 44.1                     | 44.4  |
| Average CO <sub>2</sub> emission |                     | 52.0 ± 8.1 <sup>c</sup>  | 46.3 ± 7.3 <sup>c</sup>  | 46.9 ± 6.2 <sup>c</sup>  | 48.4 ± 7.1 <sup>c</sup>   |
| MC (Gasohol 91)                  |                     |  |                          |                          |   |
| 1                                | 63 <sup>b</sup>     | 46.3   | 40.3                     | 43.2                     | 43.2  |
| 2                                | 147 <sup>b</sup>    | 46.0   | 40.4                     | 41.3                     | 42.5  |
| 3                                | 4,343 <sup>b</sup>  | 40.1   | 37.5                     | 39.7                     | 39.1  |
| 4                                | 10,469 <sup>b</sup> | 41.4   | 34.8                     | 35.9                     | 37.4  |
| 5                                | 53,938 <sup>b</sup> | 40.4   | 34.4                     | 31.3                     | 35.4  |
| Average CO <sub>2</sub> emission |                     | 42.8±3.0 <sup>c</sup>  | 37.5±2.9 <sup>c</sup>    | 38.3±4.7 <sup>c</sup>    | 39.5±3.4 <sup>c</sup>   |

## Conclusion

The results from the chassis dynamometer analysis for four vehicle types show that HD-DV had the highest CO<sub>2</sub> emission rate (an overall average of 1,198.8±93.1 g km<sup>-1</sup>), followed by LDD (268.4±21.1 g km<sup>-1</sup>), LDG (166.1±27.7 g km<sup>-1</sup>) and MC (42.5±6.1 g km<sup>-1</sup>). This study considers emission of vehicles data from emission lab. Results from experiments conducted by a range of responses in terms of CO<sub>2</sub> emissions of GHG for different fuel types. NGV in particular shows high CO<sub>2</sub> emissions, but ethanol in gasohol shows virtually no change in CO<sub>2</sub> emissions. The CO<sub>2</sub> emission rates obtained in this study can be used as a basis for further studies on GHGs emission rates from various types of vehicles.

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