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Comparison of CO_2 Emissions from Vehicles in Thailand

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Abstract

Emission of carbon dioxide (CO_2), 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_2 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_2 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^{-1}, 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_2 emission level was also compared. HDD vehicles had a higher rate of CO_2 emission when using either NGV or diesel, while LDD vehicles emitted more CO_2 with diesel than with NGV. For LDG vehicles, more CO_2 was emitted with gasohol 91 than with gasohol E20, LPG or NGV. Finally, MC had a higher average CO_2 emission rate with gasohol 95 than with gasoline 91 and gasohol 91 at any vehicle speed. The CO_2 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_2; Vehicle type; Fuel type; Driving speed

Introduction

Carbon dioxide (CO_2) is recognized as a greenhouse gas (GHG), and the transport sector is the second largest emitter of anthropogenic CO_2 worldwide. The gas is mostly generated as a by-product of fuel combustion in transport vehicles [1]. Over recent years, CO_2 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_2 emission tends to increase substantially as a result of urban expansion [3]. The increased CO_2 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_2 emissions in the exhaust gas [7]. The rate of CO_2 emitted by vehicles can be calculated from the relationship between vehicle speed, total concentration of CO_2 detected in the exhaust gas and total distance travelled [8]. Key factors affecting CO_2 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_2 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_2 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_2 emission level for each vehicle type.

2) CO_2 emission testing and analysis

The CO_2 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^{-1}. 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_2. The concentration of CO_2 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_2 detector, and then analyzed by non-dispersive infrared analyzer (NDIR), which shines an infrared beam through a sample cell containing CO_2 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_2 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	EURO II	Diesel	5
	(8,500 cc)	(2001)	NGV	5
LDD	Pick up and Van	EURO III	Diesel	5
	(2,500 cc)	(2005)	NGV	5
LDG	Passenger car	EURO III	Gasohol 91	5
	(2,000 cc)	(2005)	Gasohol E20	5
			LPG	5
			NGV	5
MC	Motorcycle	EURO III	Gasoline 91	5
	(125 cc)	(2005)	Gasohol 95	5
			Gasohol 91	5

3) CO_2 emission calculation

The CO_2 emission rate was calculated using the relationship between CO_2 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_2 emission calculation is illustrated in the following equation.

$$\mathrm{CO_2\ Emission\ (g\,km^{-1})} = \frac{\mathrm{Concentration\ of\ CO_2\,(g)}}{\mathrm{Distance\ (km)}}$$

where the emission of CO_2 is the total rate of CO_2 emission, the concentration of CO_2 is the total concentration of CO_2 detected in the exhaust gas, and the distance is the total distance of vehicle travel.

Results and discussions

1) CO_2 emission from diesel engine vehicles

Table 2 and Figure 1 present the CO_2 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_2 emission rates from HDD

For the HDD with diesel, the CO_2 emission rate was 1,036.4-1,212.9 g km^{-1} with no significant difference but different vehicle speeds between diesel and NGV were significantly different at 20-40 and 40-80 km h^{-1}. This result is in accord with the results of previous studies

[12-13], which reported that, compared to the proportion of O_2 and N_2 in the fuel, 50 % of the diesel emissions were CO_2. The average CO_2 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^{-1} at 0-20, 20-40 and 40-80 km h^{-1}, respectively. Thus, CO_2 emissions were minimal at 20-40 km h^{-1} 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_2 emission from diesel engine (HDD and LDD) vehicles with different types of fuel

Vehicle type/fuel	**Mileage of engine**	**CO_2 emission (g km^{-1}) and speed range (km h^{-1})**			**Average CO_2 emission in 1 driving cycle (g km^{-1})**
		0-20 km h^{-1}	**20-40 km h^{-1}**	**40-80 km h^{-1}**	
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_2 emission		1,290.6±96.7^{a}	577.3±91.6^{a}	1,550.9±179.1^{a}	1,139.6±64.3^{a}
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_2 emission		1,422.4±177.1^{a}	1,188.0±211.9^{b}	1,163.7±235.3^{b}	1,258.0±74.5^{b}
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_2 emission		351.9±24.6^{b}	300.0±23.5^{c}	218.7±6.4^{c}	290.2±7.7^{c}
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_2 emission		333.9±14.2^{b}	227.1±11.6^{c}	192.8±7.4^{c}	251.3±10.8^{c}

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

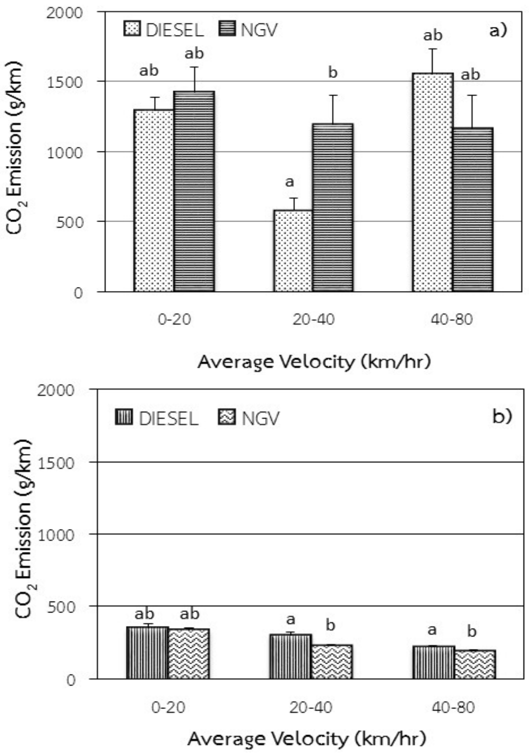

Figure 1 CO_2 emission from (a) HDD and (b) LDD using diesel or NGV fuel at a vehicle speed of 0-20, 20-40 and 40-80 km h^{-1} Data are shown as the mean±1SD, derived from five independent vehicles. Means with a different lowercase letter are significantly different ($p < 0.05$; using DMRT test).

The CO_2 emission of HDD with NGV fuel ranged from 1,180.8 to 1,378.6 g km^{-1}, with no significant difference in the CO_2 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^{-1} for 0-20, 20-40 and 40-80 km h^{-1}, respectively). However, higher levels of CO_2 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_2 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_2 emission from HDD with diesel and NGV fuel in Italy at a vehicle speed of 20-40 km h^{-1} but not at other speeds (Figure 1a).

1.2) CO_2 emission rates from LDD

The CO_2 emission rate from LDD with diesel fuel ranged from 282.5 to 302.1 g km^{-1}, but the CO_2 emission rate decreased with increasing vehicle speeds (345.5±24.6, 300.0±23.5 and 218.7±6.4 g km^{-1} at 0-20, 20-40 and 40-80 km h^{-1}, 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_2 emissions were lower at a higher speed. This result is in agreement with Zachrof et al. [16], who studied CO_2 emission of LDD in Europe.

For LDD, NGV produced a lower CO_2 emission rate (242.2-266.1 g km^{-1}) than diesel and showed no significant difference with respect to engine mileage. A marked dependence in the CO_2 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^{-1} at 0-20, 20-40, and 40-80 km h^{-1}, respectively. The same trend was observed for CO_2 emitted from LDD with diesel fuel. These re-sults are in accord with those of Bielaczc et al. [17], who studies CO_2 emission for vehicles using NGV fuel.

With respect to CO_2 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^{-1} but not at 0-20 km h^{-1} (Figure 1b).

2) CO_2 emission rates from gasoline engine vehicles

The CO_2 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_2 emission rates from LDG

The CO_2 emission rate from LDG with gasohol 91 ranged from 149.6 to 252.5 g km^{-1} with no significant difference with increasing engine mileage. The average CO_2 emission rate tended to decrease with increasing vehicle speed (204.6±43.5, 183.7±43.1 and 174.2±37.1 g km^{-1} for 0-20, 20-40 and 40-80 km h^{-1}, respectively). These results might be due to the high fuel combustion rate at the start of the test, where the CO_2 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_2 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_2 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^{-1}, respectively, with no significant difference based on engine mileage. The CO_2 emission rates from LDG with gasohol E20 decreased with in-creasing vehicle speed (162.4±28.2, 141.8±23.6 and 135.1±20.9 g km^{-1} at 0-20, 20-40 and 40-80 km h^{-1}, respectively), which is the same trend as LDG with gasohol 91. With LPG, the CO_2 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^{-1} at 0-20, 20-40 and 40-80 km h^{-1}, respectively). Likewise, the CO_2 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^{-1} at 0-20, 20-40 and 40-80 km h^{-1}, respectively.

Thus, LDG using gasohol E20 and NGV as fuel had a lower CO_2 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_2 emission rates of LDGV using either gasohol 91 or NGV at any vehicle speed, and Bielaczc 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_2 emission rates of LDG vehicles using gasohol E20 or LPG at 0-20 and 20-40 km h^{-1} (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_2 emission rates from MC

The CO_2 emission rates for MC with gaso-line 91 ranged from 37.7 to 42.8 g km^{-1} with no significant difference in the mileage of the MC engine. The CO_2 emission rate decreased with increasing MC speed (45.1±7.5, 37.4±1.6 and 36.5±3.2 g km^{-1} at 0-20, 20-40 and 40-80 km h^{-1}, respectively), again likely to reflect the higher fuel combustion rate at the beginning of test with both the combustion rate and fuel con-sumption being lower at higher vehicle speeds (the same trend as for LDD and LDG). With gasohol 95, the average CO_2 emission rate was slightly higher (38.1-54.6 g km^{-1}) 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^{-1} at 0-20, 20-40 and 40-80 km h^{-1}, respectively), displaying a similar trend as that of gasoline 91 (Figure 2b). With gasohol 91, the CO_2 emission rate was slightly lower (35.4-43.2 g km^{-1}) 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^{-1} for 0-20, 20-40 and 40-80 km h^{-1}, respectively).

Overall, MC with gasohol 91 had a lower CO_2 emission rate than with gasoline 91 and gasohol 95 at all speed rates and the new MC seem to have higher CO_2 emission than older on because it have new engine technology can be completed burning of fuel, which is in agreement with the results of Costagliola et al. [22]. Although the CO_2 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^{-1}. These results were in accordance with those of Hassani et al. [23], who reported that 40 % of CO_2 and exhausted gas emissions in Tehran (Iran) originated from an MC of 125 cc.

Table 3 CO_2 emission rates from LDG vehicles with different types of fuel

Vehicle type/fuel	Mileage of engine	CO_2 emission (g km^{-1}) and Speed range (km h^{-1})			Average CO_2 emission in 1 driving cycle (g km^{-1})
		0-20 km h^{-1}	20-40 km h^{-1}	40-80 km h^{-1}	
LDGV (Gasohol 91)					
1	9,562[ab]	168.2	153.0	145.5	155.6
2	26,608[ab]	214.4	191.6	183.7	196.6
3	88,533[ab]	165.1	141.8	141.9	149.6
4	119,931[ab]	202.7	180.3	166.7	183.3
5	200,061 [ab]	272.4	251.9	233.2	252.5
Average CO_2 emission		204.6±43.5[a]	183.7±43.1[a]	174.2±37.1[a]	187.5±41.2[a]
LDGV (Gasohol E20)					
1	147,652[a]	188.7	164.9	155.0	169.5
2	112,944[a]	159.9	134.4	125.1	139.8
3	177,771[a]	140.3	124.0	120.1	128.1
4	172,687[a]	193.0	168.4	160.3	173.9
5	122,359[a]	130.0	117.1	115.2	120.8
Average CO_2 emission		162.4±28.2[ab]	141.8±23.6[ab]	135.1±20.9[ab]	146.4±24.1[ab]
LDGV (LPG)					
1	81,979[a]	192.3	171.1	161.5	174.9
2	111,596[a]	172.9	156.0	147.1	158.7
3	131,010[a]	183.2	159.0	156.4	166.2
4	174,823[a]	220.0	178.1	159.0	185.7
5	300,993[a]	190.6	169.6	159.1	173.1
Average CO_2 emission		191.8±17.5[ab]	166.8±9.1[ab]	156.6±5.6[b]	171.7±10.1[b]
LDGV (NGV)					
1	119,922[c]	164.9	147.4	136.5	149.6
2	217,860[c]	185.3	167.9	150.2	167.8
3	270,827[c]	183.1	163.9	147.7	164.9
4	275,480[c]	185.3	164.2	151.0	166.8
5	473,774[c]	157.3	143.9	135.8	145.6
Average CO_2 emission		175.2±13.2[b]	157.5±11.0[c]	144.2±7.5[b]	159.0±10.5[b]

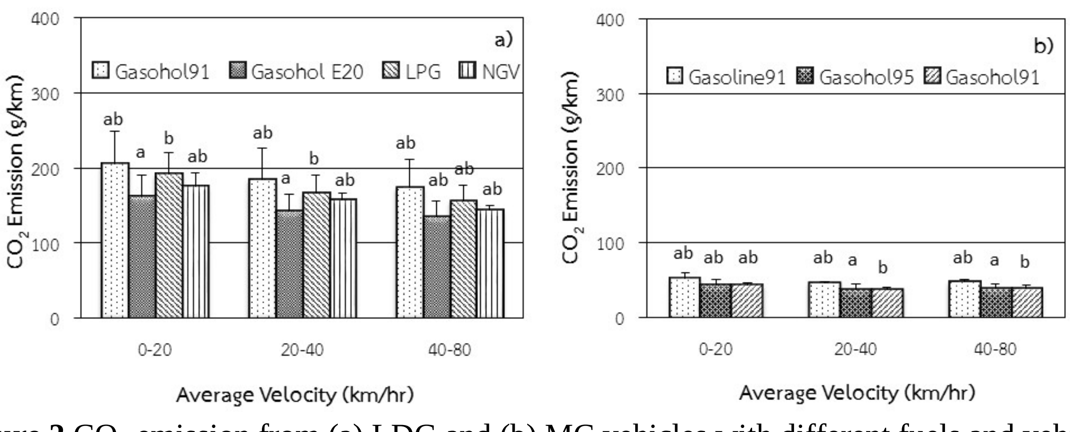

Figure 2 CO_2 emission from (a) LDG and (b) MC vehicles with different fuels and vehicle speeds. Data are shown as the mean ± 1 SD, derived from five independent vehicles. Means with a different lowercase letter are significantly different (*p < 0.05*; using DMRT test).

Table 4 CO_2 emission rates from MC vehicles with different types of fuel

Vehicle type/fuel	Mileage of engine	CO_2 emission (g km^{-1}) and Speed range (km h^{-1})			Average CO_2 emission in 1 driving cycle (g km^{-1})
		0-20 km h^{-1}	20-40 km h^{-1}	40-80 km h^{-1}	
MC (Gasoline 91)					
1	3[b]	41.0	36.9	40.3	39.4
2	183[b]	45.9	39.6	35.4	40.3
3	225[b]	41.9	35.7	35.7	37.7
4	623[b]	39.0	36.3	39.1	38.1
5	3,355[b]	57.7	38.5	32.2	42.8
Average CO_2 emission		45.1±7.5[c]	37.4±1.6[c]	36.5±3.2[c]	39.7±2.0[c]
MC (Gasoline 95)					
1	150[b]	52.3	50.1	50.9	51.1
2	4,967[b]	59.0	51.5	51.7	54.1
3	5,169[b]	60.2	52.7	50.7	54.6
4	5,273[b]	40.6	36.4	37.2	38.1
5	6,688[b]	48.2	40.9	44.1	44.4
Average CO_2 emission		52.0 ± 8.1[c]	46.3 ± 7.3[c]	46.9 ± 6.2[c]	48.4 ± 7.1[c]
MC (Gasohol 91)					
1	63[b]	46.3	40.3	43.2	43.2
2	147[b]	46.0	40.4	41.3	42.5
3	4,343[b]	40.1	37.5	39.7	39.1
4	10,469[b]	41.4	34.8	35.9	37.4
5	53,938[b]	40.4	34.4	31.3	35.4
Average CO_2 emission		42.8±3.0[c]	37.5±2.9[c]	38.3±4.7[c]	39.5±3.4[c]

Conclusion

The results from the chassis dynamometer analysis for four vehicle types show that HD-DV had the highest CO_2 emission rate (an overall average of 1,198.8±93.1 g km^{-1}), followed by LDD (268.4±21.1 g km^{-1}), LDG (166.1±27.7 g km^{-1}) and MC (42.5±6.1 g km^{-1}). This study considers emission of vehicles data from emission lab. Results from experiments conducted by a range of responses in terms of CO_2 emissions of GHG for different fuel types. NGV in particular shows high CO_2 emissions, but ethanol in gasohol shows virtually no change in CO_2 emissions. The CO_2 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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