UPDATING EMISSION FACTORS FOR IN-USE MOTORCYCLES FUELED BY GASOLINE, E5 AND E10 IN VIETNAM

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Abstract

Motorcycle is the most popular transportation means in Vietnam due to its low cost and flexibility. However, motorcycles emit substantial quantities of hydrocarbons, carbon monoxide, nitrogen oxides and some amount of particulate matter. Emission factors for in-use motorcycles in Vietnam were studied and established quite a long time ago. The objective of this study is to update the emission factors, not only gaseous emissions but also particle number, for in-use motorcycles in Vietnam. Ten carbureted and electronic fuel injected motorcycles representative for in-use motorcycles were selected for investigation. Each motorcycle was fueled by conventional gasoline, E5 and E10 in turn, and was tested on a chassis dynamometer according to ECE R40 driving cycle. The gaseous emissions were sampled and determined by standard methods, while the particle number in exhaust gas was sampled by using the sampling system developed by Laboratory of Internal Combustion Engine, Hanoi University of Science and Technology, Vietnam. The updated emission factors were then provided for carbureted motorcycles, EFI motorcycles and average motorcycle fleet in case of gasoline, E5 and E10 fueling.

Keywords: Emission factors, E5, E10, Exhaust gas emissions, Motorcycles, Vietnam.

Introduction

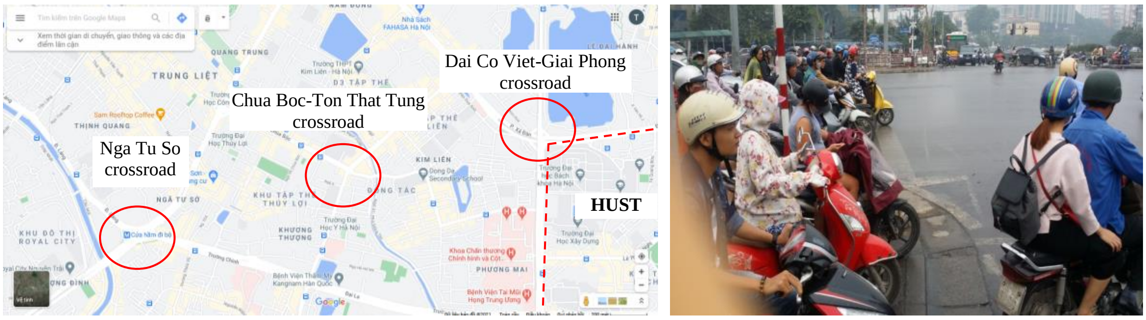
Motorcycle is a very popular transportation means in many ASEAN countries. So far, there have been about 40 million in-use motorcycles in Vietnam. However, motorcycles emit substantial quantities of hydrocarbons (HCs), carbon monoxide (CO), nitrogen oxides (NO_x) and small amount of particulate matter (PM). These pollutants have significant adverse health effects and deteriorate the environment. The contribution of motorcycle's emissions to urban air pollution has become an increasingly common phenomenon, especially in big cities. To estimate amount of pollutant emissions from the transport sector in general, from motorcycle in particular, it is necessary to determine the emission factors. These emission factors may vary over time with advances in engine technologies, changes in fuel specification regulations, deterioration due to vehicle mileage accumulation, implementation of tighter on-road emission controls such as inspection and maintenance programs, and adoption of advanced emission control technologies. Therefore, the emission factors need to be updated after a few years to make them in line with reality [1,2]. In Vietnam, emission factors for motorcycles were studied and established quite a long time ago and mostly focused on carbureted motorcycles with conventional gasoline RON92 [3-5]. Currently, most of new models of motorcycles have been equipped with

ECU and EFI system, which can control amount of the injected fuel and the spark ignition timing suitable to engine operation modes. A catalytic converter has been also used to reduce HC, CO and NO_x emissions in exhaust gas. These devices help to improve the quality of mixture and reduce the fuel consumption and emissions, so that the emission levels can meet the requirement of stringent emission standard that has been Euro 3 since January 2017. Moreover, ethanol-gasoline blend with 5% ethanol (E5 RON92) has been used nation-wide substituting for gasoline RON92 from January 2018, and the blend with 10% ethanol (E10) might be used step by step in the next few years. Some previous studies were carried out to investigate the effect of E5, E10 and high ethanol content in gasoline-ethanol blends on emissions of in-use motorcycles, cars and SI engines in Vietnam [6-8]. The results showed a change in emissions in which generally HC and CO reduced whereas NO_x increased. Therefore, this study aims to update the emission factors of in-use motorcycles in Vietnam, including carbureted and EFI motorcycles, fueled by gasoline, E5 and E10.

Experimental

Selection Of In-use Motorcycles For Testing

In order to select the representative motorcycles for testing, the survey on models of in-use motorcycles was carried out at three big crossroads in Hanoi capital, Vietnam. The crossroads included Nga Tu So, Dai Co Viet-Giai Phong, Chua Boc-Ton That Tung crossroads), which usually have quite high traffic density (Figure 1). The observation was at normal hours and rush hours, on working days as well as at weekends.



(a) (b)

Figure 1. Crossroads in the survey
(a) Location of three crossroads surveyed
(b) Dai Co Viet-Giai Phong crossroads at 8am

Based on collected data, the quantity of each in-use motorcycle model and the share of motorcycle maker were determined. The highest share belongs to Honda products, then followed by Yamaha, Piaggio, SYM and small number of Suzuki (Figure 2). For each motorcycle maker, the representative models, which have high quantity are selected as shown in Table 1.

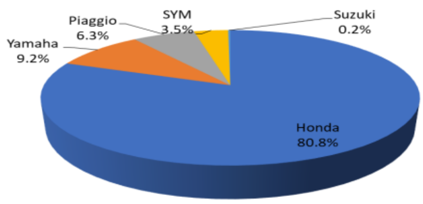


Figure 2. Share of in-use motorcycles contributed by manufacturers

Table 1. Motorcycles Selected for Emission Testing

No	Model	Maker	Year	Capacity (cm^3)	Rate power/speed (kW/rpm)	Fuel system	Catalytic converter
1	Sirius	Yamaha	2016	110	6.4 /7000	EFI	Yes
2	Primavera	Piaggio	2014	125	7.9 /7700	EFI	Yes
3	AirBlade	Honda	2014	125	8.2 /8500	EFI	Yes
4	Lead 125	Honda	2013	125	8.45 /8500	EFI	Yes
5	Vespa LX	Piaggio	2011	125	8.5 /7500	EFI	Yes
6	Lead 110	Honda	2009	110	6.4 /7500	EFI	Yes
7	Dream	Honda	2013	100	4.41 /7000	Carburetor	No
8	Hayate	Suzuki	2011	125	9.47 /8000	Carburetor	No
9	Attila	SYM	2009	125	6.5 /7500	Carburetor	No
10	Wave S	Honda	2008	100	5.1 /8000	Carburetor	No

Experimental Apparatus

These in-use motorcycles were tested on a chassis dynamometer with emission sampling and measurement system (Figure 3). The chassis dynamometer is an asynchronous machine placed between two rollers, which have diameter of 20 inches. By this dyno, vehicle speed and power at wheel can be controlled and measured. In the constant volume sampling (CVS) system, the exhaust gas was mixed with clean ambient air in order to simulate the real on road conditions. The total flow rate in the system was kept constant to calculate the mass of emissions. The concentration of gaseous pollutants in diluted exhaust gas was detected by emission analyzers. CO, HC and NO_x emissions were analyzed by Non-Dispersive Infrared (NDIR), Flame Ionization Detector (FID) and Chemiluminescence Detector (CLD) analyzers, respectively. Each analyzer has 4 measurement ranges that can be adjusted automatically to consist with measured values in order to increase the accuracy.

Additionally, the particle number (PN) in exhaust gas was also sampled and counted by the particle counting system, that included a dilution system and a particle counter. As requirement of Particle Measurement Program (PMP) [9], the dilution system should comprise a first dilution stage heated to 150^0C, an evaporation tube heated to 300-400^0C, and a second dilution stage cooling the sample gas down to about 30^0C. In this study, the dilution system was developed at Laboratory of Internal Combustion Engine (HUST) (Figure 4). An ejector was used for first dilution stage in which clean compressed air produced an under pressure at the nozzle that drew the sample gas. The second diluter was the mixer in which sample gas and clean air were mixed. The first dilution stage and the evaporation tube were heated by heating wires and the heating temperatures were controlled as required. Dilution factors of the first diluter and the second diluter were defined by measuring related flow rates. The overall dilution factor of the system was product of two dilution factors mentioned above. The particle counter, a Miniature Diffusion Size Classifier (DiSCmini) manufactured by Testo, was used to determine the PN. The DiSCmini can detect PN concentration up to 10^6 #/cm^3 with the size in the range of 20-700 nm with the sampling flow rate of 1 l/min. Although this particle counting system has not been calibrated and validated by PMP method, but the measurement result could provide some useful information of PN emissions from in-use motorcycles.

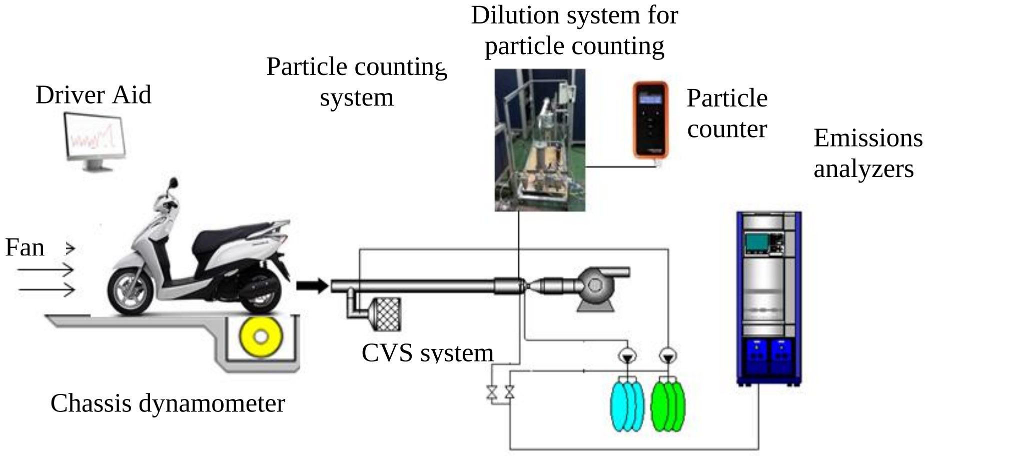


Figure 3. Layout of experimental setup

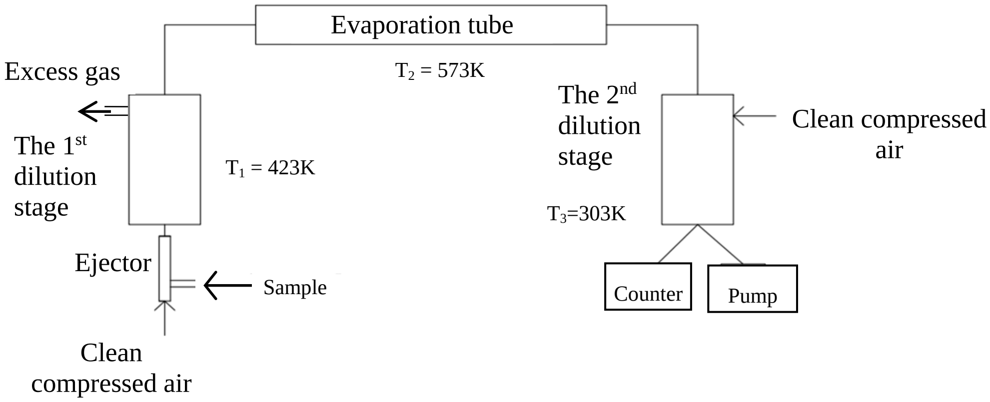


Figure 4. Schematic of particle counting system

Each motorcycle was tested with gasoline RON92, E5 and E10 in turn. The main properties of these fuels are presented in Table 2. The motorcycle were driven according to European ECE R40 driving cycle (Figure 5).

Table 2. Properties of Test Fuels

Property		Gasoline RON 92	E5	E10
Ethanol content (vol%)		-	4.6	9.2
Distillation temperature (^{0}C)	IBP	35.9	40.8	37.5
	t_{10}	53.3	52.8	50.7
	t_{50}	91.1	102.1	67.9
	t_{90}	162.1	166.8	160.2
	EBP	196.1	203.2	192.3
Octane number		92.2	93.5	95.4
RVP (kPa)		40	42	48
Density (kg/l)		0.725	0.733	0.748

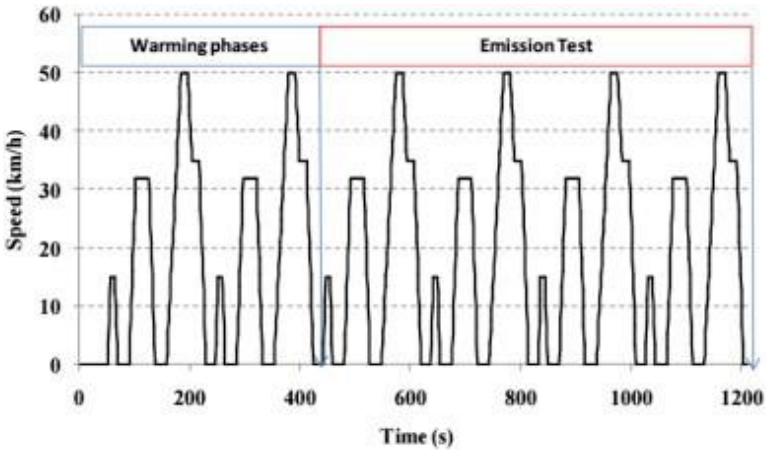


Figure 5. ECE R40 driving cycle for motorcycle.

Results and Discussion

Based on the emission data collected of the 10 in-use test motorcycles, the emission factors (in g/km for gaseous components, in #/km for PN) determined for each motorcycle are summarized in Tables 3, in which the first four motorcycles are equipped with carburetor and the rest with EFI technologies.

It can be seen that HC, CO, NO_x, CO_2 and PN emission factors of the carbureted motorcycles fueled by gasoline are in the range of 0.880 to 1.162 g/km, 6.038 to 13.441 g/km, 0.078 to 0.221 g/km, 21.629 to 42.591 g/km and $2.81x10^{11}$ to $2.21x10^{12}$ #/km respectively. Comparing to some previous studies [3,5] with the motorcycle's capacity in the range of $100cm^3$ to $125cm^3$, it can be seen that the emission factors of the carbureted motorcycles fueled by gasoline in this study agree quite well with these others (Figure 6). It is because these motorcycles were equipped with the same carbureted technology and used the same fuel. The small variation is caused by the differences in motorcycle makers and manufacturing year.

For EFI motorcycles, HC, CO, NO_x, CO_2 and PN emission factors are in the range of 0.261 to 0.905 g/km, 1.254 to 6.571 g/km, 0.046 to 0.180 g/km, 33.393 to 69.664 g/km and $2.37x10^{11}$ to $1.14\ x10^{12}$ #/km. In average, the HC, CO, NO_x and PN emission factors of EFI motorcycles reduce by 51.1%, 68.2% 25.0% and 43.3% whereas CO_2 emission factor increases by 41.5% as compared to that of carbureted motorcycles in this study. Comparing to the previous studies [3,5] the HC, CO emission factors of EFI motorcycles are about 2 to 4 time lower than those of previous ones. It is clear that EFI technology improves air/fuel mixture quality, constantly monitors and adjusts air/fuel ratio to maintain optimal combustion conditions, then the combustion process is more complete as compared to that in carbureted motorcycles. Furthermore, the EFI motorcycles are equipped with catalytic converter in exhaust pipe; therefore, the HC and CO emissions are reduced significantly.

Considering the fuel use, the average emission factors of the carbureted and EFI motorcycles fueled by gasoline, E5 and E10 can be compared to each other as well as to the limit of Euro 2 emission standard (Figure 7). The similar trend of emission factors as mentioned above can be observed by comparing EFI and carbureted motorcycles fueled by E5 as well as E10. Moreover, the use of gasoline-ethanol blends has potential to reduce HC, CO emissions. In case of carbureted motorcycles fueled E5, the HC and CO emissions reduce by 12.8% and 10.9% whereas the NO_x and PN increase quite clearly by 40.6% and 51.3% as compared to gasoline-fueled motorcycles. Similarly, for EFI motorcycles fueled E5, the HC and CO emissions reduce by 12.1% and 8.2% whereas the NO_x and PN increase by 24.6% and 15.7%. With E10 fuel, the change in emissions is in the same way as E5 fueling except for PN, which is slightly less than that with gasoline fueling. Most of the gaseous emission factors of in-use motorcycles under test meet the requirement of Euro 2 emission standard, only the emission factors for CO of carbureted motorcycles exceed the Euro 2 limit.

Table 3. Emission Factors of Each in-use Motorcycle under Test

Emission Factors	**Gasoline Fuel**									
	Dream	Wave S	Attila	Hayate	Air Blade	Lead 110	Lead 125	Primavera	Sirius FI	Vespa LX
HC (g/km)	1.162	0.903	1.126	0.880	0.261	0.489	0.905	0.397	0.368	0.564
NO_x (g/km)	0.196	0.078	0.139	0.221	0.157	0.086	0.134	0.110	0.180	0.046
CO (g/km)	7.730	13.441	10.939	6.038	1.285	6.571	4.217	1.254	2.990	1.902
CO_2 (g/km)	27.660	21.629	39.481	42.591	43.742	47.649	35.067	69.664	33.393	49.241
PN (#/km)	4.33×10^{11}	2.81×10^{11}	2.21×10^{12}	1.62×10^{12}	1.14×10^{12}	4.52×10^{11}	2.37×10^{11}	6.32×10^{11}	7.93×10^{11}	6.07×10^{11}
	E5 Fuel									
HC (g/km)	1.028	0.818	1.068	0.633	0.246	0.469	0.917	0.340	0.302	0.350
NO_x (g/km)	0.275	0.102	0.210	0.305	0.195	0.106	0.171	0.124	0.225	0.066
CO (g/km)	6.525	12.471	9.352	5.658	1.266	6.295	3.648	0.976	2.652	1.891
CO_2 (g/km)	28.027	21.706	38.956	46.385	43.120	47.196	36.712	66.164	33.923	50.234
PN (#/km)	6.12×10^{11}	4.85×10^{11}	3.85×10^{12}	1.92×10^{12}	1.49×10^{12}	4.84×10^{11}	3.52×10^{11}	5.12×10^{11}	1.07×10^{12}	5.58×10^{11}
	E10 Fuel									
HC (g/km)	0.951	0.626	1.157	0.730	0.196	0.458	0.809	0.301	0.259	0.297
NO_x (g/km)	0.231	0.092	0.196	0.300	0.165	0.097	0.150	0.165	0.217	0.070
CO (g/km)	5.132	8.917	6.805	4.354	1.180	5.822	3.293	1.031	2.095	1.663
CO_2 (g/km)	28.184	23.379	38.131	43.350	38.610	44.323	35.137	68.328	33.362	50.210
PN (#/km)	4.13×10^{11}	2.27×10^{11}	2.28×10^{12}	1.42×10^{12}	1.19×10^{12}	4.75×10^{11}	1.34×10^{11}	4.24×10^{11}	9.82×10^{11}	5.21×10^{11}

By averaging the emissions of all the tested motorcycles represented for motorcycle fleets on the road, the emission factors can be updated. For gasoline fueling, HC, NO_x, CO, CO_2 and PN emission factors are 0.706 g/km, 0.135 g/km, 5.637 g/km, 41.012 g/km and 8.41×10^{11} #/km; for E5 fueling they are 0.617 g/km, 0.178 g/km, 5.073 g/km, 41.242 g/km and 11.3×10^{11} #/km; for E10 fueling they are 0.578 g/km, 0.168 g/km, 4.029 g/km, 40.301 g/km and 8.05×10^{11} #/km, respectively.

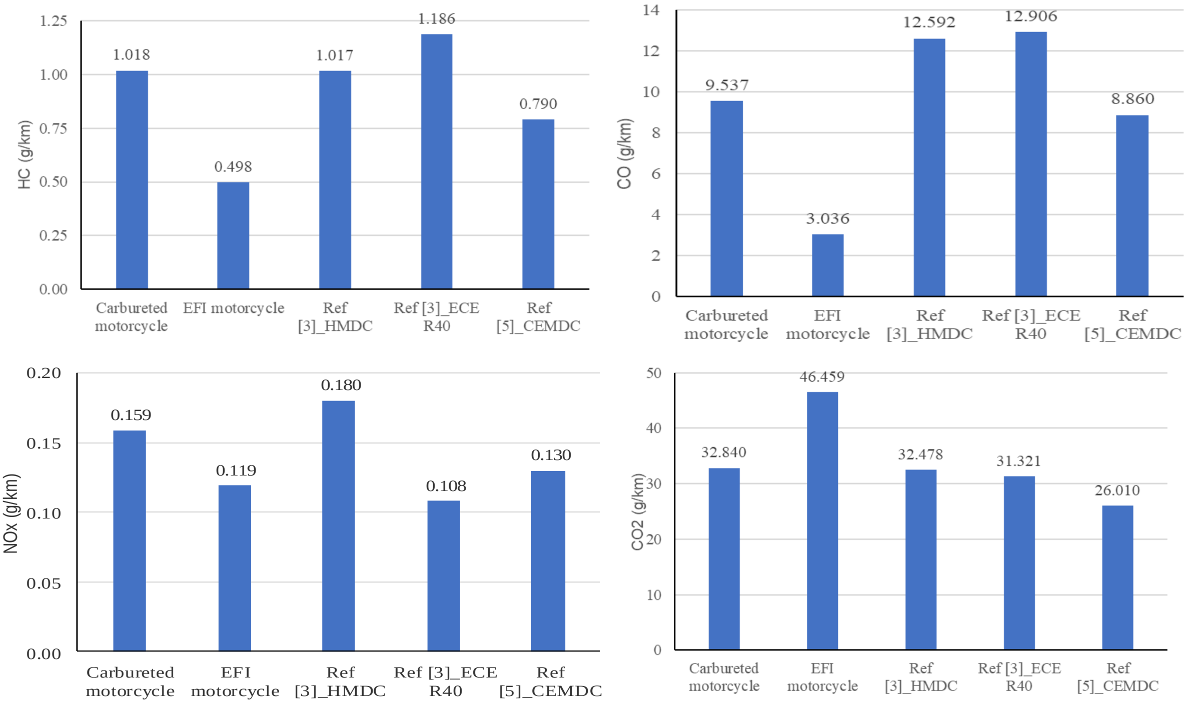


Figure 6. Comparison of the average emission factors to those of some previous studies in case of gasoline fueling

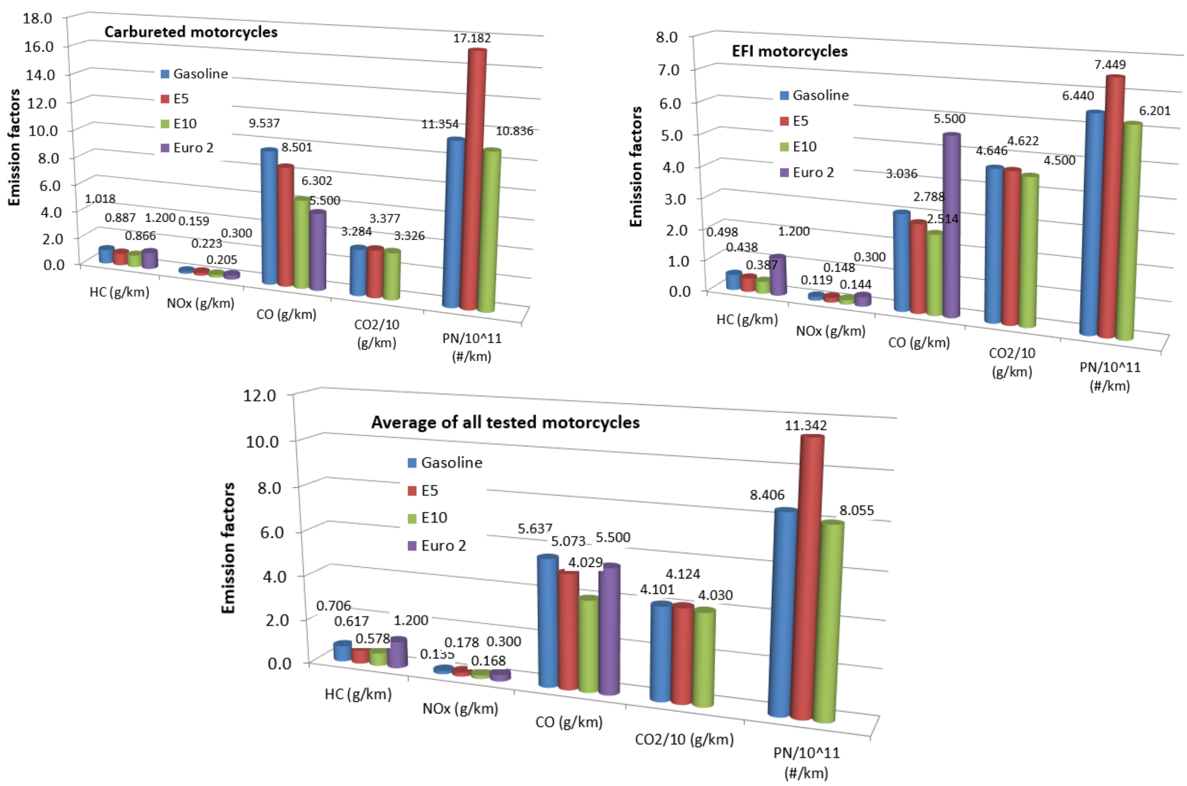


Figure 7. Comparison of the emission factors of carbureted motorcycles (a), EFI motorcycles (b), and avarage of all tested motorcycles (c) with various fuels and Euro 2 limit

Conclusions

The emission factors have been updated in consideration of both carbureted and EFI in-use motorcycles in Vietnam. It is shown that there is not much change in emission factors of carbureted motorcycles. However, the EFI technology and catalyst converter equipped in motorcycles have reduced significantly most of the gaseous emission factors. In this case, the emission factors for HC and CO are much lower than those known before. Moreover, the use of gasoline-ethanol blends such as E5 and E10 also effects quite a lot on the amount of pollutants emitting from motorcycles. The emissions factors of the motorcycle fleet on the road with various fuels are also suggested. For emission inventory, the emission factors need to be corrected in order to be in line with new engine technologies and current fuel use. Although the PN has not been limited for motorcycle, the average values measured in this study were about 8.41×10^{11}#/km, 11.3×10^{11} #/km and 8.05×10^{11} #/km with gasoline, E5 and E10 fueling, respectively, which could provide useful information for research or emission inventory.

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