Developing Emission Factor Models for in-use Motorcycles Fueled by Gasoline, E5 and E10

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Abstract

Emissions from transportation sectors contain many toxic substances such as CO, HC, NOx, PM, etc. which cause environmental pollution and adverse effect on human health. In Vietnam, motorcycle is the most popular transportation means. However, motorcycles emit considerable amount of these pollutants. To estimate total emissions from motorcycles, it is necessary to determine the emission factors in certain working conditions. This paper develops the emission models of in-use motorcycles fueled by gasoline, E5 and E10 based on modal emission values which are collected from measurements on chassis dynamometer based on standard driving cycles.

Keywords: emissions from motorcycles, total emissions, emission factor, in-use motorcycle

1. Introduction

Motorcycle is one of the most popular transportation means in Vietnam as well as other Southeast Asian countries due to its low cost and flexibility. 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 environmental quality. The contribution of motorcycle's emissions to urban air pollution has become an increasingly common phenomenon, especially in big cities. In order to reduce emissions from transport sector in general, from motorcycles in particular, most countries in the world are applying more and more stringent emission standards that mainly follow European, United States or Japanese emission regulations.

In technical aspect, the common measures used to reduce emission level are optimization of engine structure and engine map, application of after-treatment devices and use of clean fuels or biofuel. To estimate amount of pollutants emitting from vehicles to the atmosphere, it is necessary to determine the emission factors. These emission factors depend on engine technologies, fuel type, age of vehicles, driving behavior, traffic condition, etc. Therefore, vehicles should be classified into categories and emission factors need to define for each vehicle category. The amount of pollutants can be calculated by using simple equation as below [1]:

$$E = e\ x\ L \tag{1}$$

in which:

E: total emissions in the area (g per day)

e: emission factor (g/km)

L: total vehicle mileage (km per day)

There have been some models that are used to calculate emission factors for automobiles such as Computer Programme to calculate Emissions from Road Transport (COPERT) full emission model, continuous emission models Digitalisiertes Grazer Verfahren (DGV), Swiss Federal Laboratories for Materials Science and Technology (EMPA), Passenger car and Heavy duty vehicle Emission Model (PHEM) [1]. However, there are few emission factor models for motorcycles. In Vietnam, emission factors for motorcycles were studied and established about 7 years ago and mostly focused on carbureted motorcycles with conventional gasoline RON92 [2]. Currently in Vietnam, besides some carbureted motorcycle models such as Honda Dream, Honda Wave, SYM Attila, many new motorcycle models are equipped with electronic control unit (ECU) and electronic fuel injection (EFI) technologies, e.g Honda Lead, Honda AirBlade, Piaggio Vespa, Yamaha Sirius, which can control amount of the injected fuel and the spark ignition timing suitable with engine operation modes. These technologies

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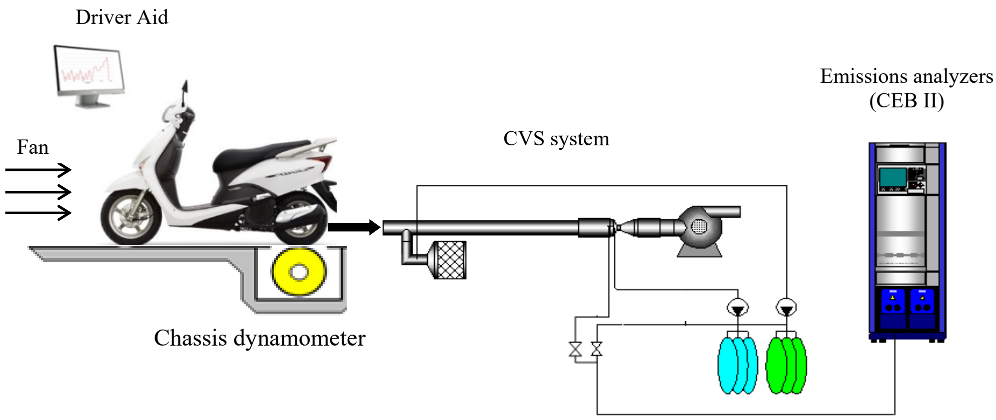

Fig. 1. Layout of experimental setup

help to improve the quality of mixture, reduces the fuel consumption and emissions as well, so that 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) have been used nation-wide substituting for gasoline RON92 since January 2018, and blend with 10% ethanol (E10) might be used step by step in the next few years. In this paper, we have proposed the emission factor models for in-use motorcycles fueled by gasoline, E5 and E10 in Vietnam based on modal emission values which are collected from measurements on chassis dynamometer following standard driving cycles.

2. Methodology

2.1. Apparatuses for instantaneous emission measurement

Apparatuses for instantaneous emission measurement include a chassis dynamometer 20” (CD 20”), a constant volume sampling (CVS) system, and a combustion emission bench (CEBII) (Fig 1).

Each section has its own computer controlled by dedicated software and connected to common local network (LAN). The chassis dynamometer 20” is an asynchronous machine connected to a roller which has diameter of 20 inches. Motorcycles are operated on the chassis dyno according to the specified driving cycle, the speed varies with the time displayed on the driver assistance screen is recorded. Emissions from the engine are drawn into the CVS sampling system and diluted with ambient air in order to simulate the real on-road condition. The total flow rate in the system remains constant which can be used to calculate the mass of emissions. The CEB II comprises all analyzers for HC, CO, NO_x and CO_2 emissions measured over time. CO emission is analyzed by using Non Dispersive Infrared (NDIR) method. HC emission is analysed by a Flame Ionization Detector (FID) and NO_x by a Chemiluminescence detector (CLD).

2.2. Calculation of pollutant mass

During the measurement, emissions in diluted gas are detected by analyzers and usually expressed in ppm that need to calculate and convert into mass unit (e.g. g/h or g/km). Calculation of the mass of pollutant i is mentioned below [3].

Calculation of the corrected concentration of pollutant i in the diluted exhaust gas:

$$C_i = C_e - C_d\left(1 - \frac{1}{DF}\right) \quad (2)$$

in which:

C_i: concentration of the pollutant i in the diluted exhaust gas, corrected by the amount of i contained in the dilution air, (ppm)

C_e: measured concentration of pollutant i in the diluted exhaust gas, (ppm)

C_d: measured concentration of pollutant i in the air used for dilution, (ppm)

DF: dilution factor, calculated as follows:

$$DF = \frac{14{,}5}{C_{CO_2} + 0{,}5C_{CO} + C_{HC}} \quad (3)$$

in which CO_2, C_{HC} and C_{CO} are concentrations of CO_2, HC and CO (% volume) in the diluted exhaust gas respectively. Then, the mass of pollutant can be calcultaed as:

$$M_i = C_i \times Q_i \times V_{mix} \times 10^{-3} \times 3600 \quad (4)$$

M_i: mass emission of the pollutant i, (g/h)

V_{mix}: volume flow rate of the diluted exhaust gas flowing through CVS system corrected at standard conditions (273,2 K and 101,33 kPa), (m^3/h)

Q_i: density of the pollutant i at normal temperature and pressure (273,2 K and 101,33 kPa), (g/l)

k_H: humidity correction factor used for the calculation of the mass emissions of oxides of nitrogen, (-)

C_i: concentration of the pollutant i in the diluted exhaust gas, determined by Eq. (2), (ppm)

2.3. Experimetal emission factor models

Theoretically, the mass emission of pollutant (M_i) can be calculated at each velocity value second by second by Eqs. (2) to (4). The emission factor at that velocity is calculated as:

$$e_i = \frac{M_i}{v} \tag{5}$$

It should be noted that the recorded emission values in emission tests could be delayed and smoothened compared to that at engine [1]. This is due to the transport time of the exhaust gas via exhaust gas system, connection pipe, CVS tunnel to the analyzers; the mixing of exhaust gas especially in the silencer and in the CVS tunnel; and the response time of the analyzers.

These phenomena may shift the emission signal from few to few tens seconds depending on the engine capacity, the flow rate of the CVS system, the engine speed and load, etc. To compensate the above delay time, a constant shifting time is applied for each measurement to align the emission signal with motorcycle velocity (Fig 2).

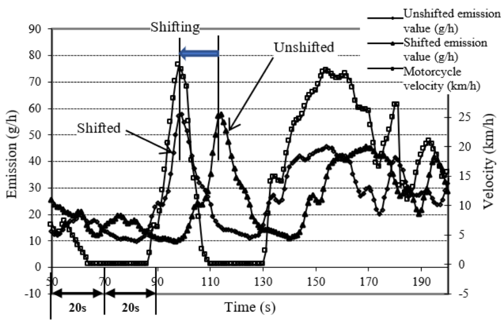

Fig 2. Shifting and averaging measured emission values

Moreover, considering the variation in delayed time and the smoothening of emission signal, the values of emissions and velocity are averaged over each 20 seconds. That means the full driving cycle is devided into several 20 second-subcycles. For each subcycle velocity and emissions are averaged to provide more data corresponding more driving stituations than the average of overall cycle.

Therefore, the emission factor can be calculated for each subcycle as:

$$e_i = \frac{M_i}{\bar{v}} \tag{6}$$

Where M_i and v_i are the average mass of the pollutant i (expressed in g/h) and average velocity over each subcycle (expressed in km/h). Then the emission factors can be displayed versus velocities, and the correlation can be withdrawn by approximate curves.

3. Results and discussion

In order to develop emission factor models, ten in-use motorcycles that are representative of in-use motorcycles in Vietnam are selected and tested on the chassis dyno. These motorcycles include carbureted and fuel injected motorcycles as displayed in Table 1. Two driving cycles for motorcycle are used for the test: European ECE R40 and World-wide Motorcycle Test Cycle (WMTC) (Fig 3). Each motorcycle is tested with gasoline RON92, E5 and E10 in turn. The main properties of these fuels are shown in Table 2.

Table 1. Motorcycles selected for emission testing

No	Model	Maker	Year	Capacity (cm^3)	Fuel system
1	Sirius	Yamaha	2016	110	EFI
2	Primavera	Piaggio	2014	125	EFI
3	AirBlade	Honda	2014	125	EFI
4	Lead 125	Honda	2013	125	EFI
5	Vespa LX	Piaggio	2011	125	EFI
6	Lead 110	Honda	2009	110	EFI
7	Dream	Honda	2013	100	Carburetor
8	Hayate	Suzuki	2011	125	Carburetor
9	Attila	SYM	2009	125	Carburetor
10	Wave S	Honda	2008	100	Carburetor

a)

b)

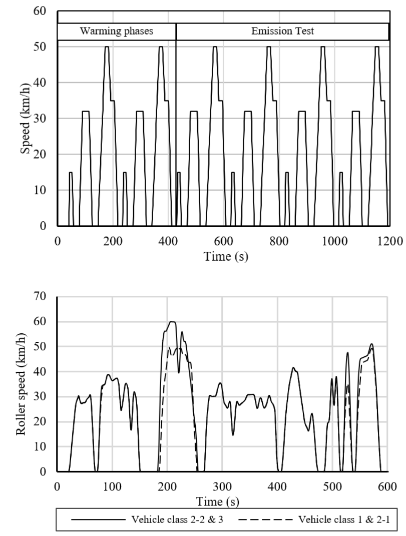

Fig 3. ECE R40 (a) and WMTC (b) driving cycles.

Table 2. Main properties of the fuels tested

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/liter)		0.725	0.733	0.748

The tested motorcycles are classified into two groups of carbureted and fuel injected motorcycles. The emission factors corresponding to the 20 second-subcycles are calculated by Eq. (6) for each motorcycle of each group and for each fuel, then are displayed versus related velocities on the graph, and the models can be obtained by approximate curves which provide the highest determination coefficient R^2 (Figs 4 to 7). By that way, the HC, CO and CO_2 models are described as power functions while NO_x model is described as polynomial curve.

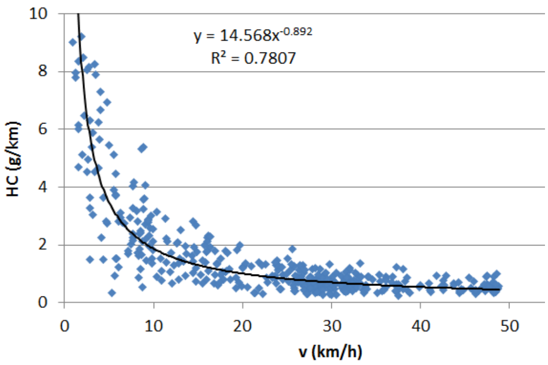

Fig 4. HC emission model, carbureted motorcycles with gasoline fuel.

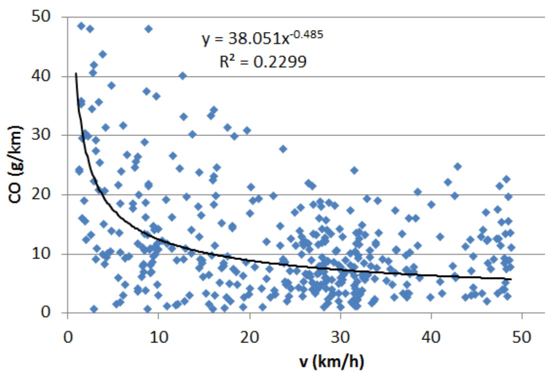

Fig 5. CO emission model, carbureted motorcycles with gasoline fuel.

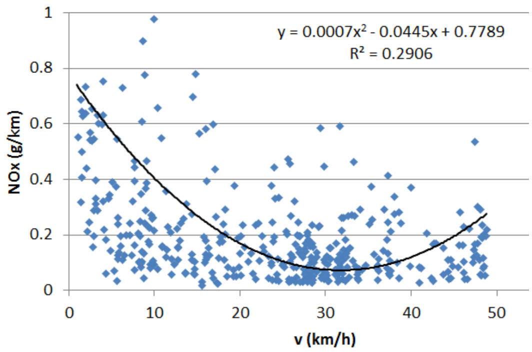

Fig 6. NO_x emission model, carbureted motorcycles with gasoline fuel.

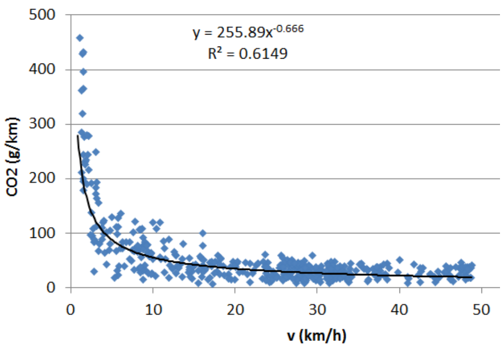

Fig 7. CO_2 emission model, carbureted motorcycles with gasoline fuel.

Resultantly, the emission models with two motorcycle groups fueled by gasoline, E5 and E10 fuels are summarized as below:

- For carbureted motorcycles with gasoline fuel

  $HC = 14.568\ v^{-0.892}$; $R^2 = 0.781$

  $CO = 38.051 v^{-0.485}$; $R^2 = 0.230$

  $NO_x = 0.0007\ v^2 - 0.0445\ v + 0.7789$; $R^2 = 0.291$

  $CO_2 = 255.89\ v^{-0.666}$; $R^2 = 0.615$

- For carbureted motorcycles with E5 fuel

  $HC = 12.111\ v^{-0.855}$; $R^2 = 0.784$

  $CO = 39.364\ v^{-0.541}$; $R^2 = 0.279$

  $NO_x = 0.0009\ v^2 - 0.0602\ v + 1.0748$; $R^2 = 0.346$

  $CO_2 = 282.95\ v^{-0.683}$; $R^2 = 0.643$

- For carbureted motorcycles with E10 fuel

  $HC = 12.935\ v^{-0.903}$; $R^2 = 0.788$

  $CO = 19.652\ v^{-0.414}$; $R^2 = 0.174$

  $NO_x = 0.0007\ v^2 - 0.04\ v + 0.7423$; $R^2 = 0.269$

  $CO_2 = 226.95\ v^{-0.612}$; $R^2 = 0.641$

- For EFI motorcycles with gasoline fuel

$HC = 7.4945\ v^{-0.891}$; $R^2 = 0.629$

$CO = 25.061\ v^{-0.775}$; $R^2 = 0.319$

$NO_x = 0.0005\ v^2 - 0.0296\ v + 0.5127$; $R^2 = 0.245$

$CO_2 = 407.74\ v^{-0.71}$; $R^2 = 0.717$

- For EFI motorcycles with E5 fuel

$HC = 4.8274\ v^{-0.805}$; $R^2 = 0.601$

$CO = 14.884\ v^{-0.654}$; $R^2 = 0.221$

$NO_x = 0.0006\ v^2 - 0.0358\ v + 0.6392$; $R^2 = 0.242$

$CO_2 = 365.53\ v^{-0.646}$; $R^2 = 0.694$

- For EFI motorcycles with E10 fuel

$HC = 5.3047\ v^{-0.855}$; $R^2 = 0.603$

$CO = 17.87\ v^{-0.734}$; $R^2 = 0.273$

$NO_x = 0.0007\ v^2 - 0.0403\ v + 0.6724$; $R^2 = 0.217$

$CO_2 = 382.45\ v^{-0.691}$; $R^2 = 0.70$

Table 3. Difference between simulated and measured emission levels

Motorcycles with fuel types	Averaged difference			
	HC	CO	NO_x	CO_2
Carbureted motorcycles with gasoline	19.74%	13.81%	8.41%	18.94%
Carbureted motorcycles with E5	17.64%	19.64%	-9.85%	13.70%
Carbureted motorcycles with E10	21.78%	21.41%	16.06%	17.58%
EFI motorcycles with gasoline	25.07%	28.36%	-6.39%	16.85%
EFI motorcycles with E5	22.62%	20.71%	-4.02%	14.40%
EFI motorcycles with E10	26.84%	30.72%	-5.00%	16.50%

It can be seen that the determination coefficients R^2 of HC and CO_2 models are quite high whereas those of CO and NO_x have lower values. However, the models with low determination coefficients are also acceptable because the models will be used to calculate the average emissions of motorcycle over certain cycles, and the overestimate in some cases will compensate for the underestimate in other cases. To validate these models, the emission levels of the motorcycles are simulated by these models above and compared with measured values following WMTC cycle which has the average velocity over cycle is 23 km/h. As shown in Table 3, the biggest of averaged differences is 26.84%, 30.72%, 16.06% and 18.94% with HC, CO, NO_x and CO_2 emissions, respectively.

4. Conclusion

The emissions from representative in-use motorcycles in Vietnam have been measured on chassis dyno with gasoline, E5 and E10 fuels. Based in the intantaneously measured values, HC, CO, NO_x and CO_2 emission factor models have been developed and validated for both carbureted and EFI motorcycles. These models would be helpful to calculate the amount of pollutants emitting from motorcycles necessary for emission inventory. These models can be also applied in estimating the emission levels from in-use motorcycles with different driving cycles to reduce time and cost for emission tests.

Acknowledgments

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