PRELIMINARY ESTIMATION OF EMISSION FACTORS FOR MOTORCYCLES IN REAL-WORLD TRAFFIC CONDITIONS OF HANOI

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ABSTRACT

This paper presents a method to estimate emission factors of motorcycles based on the local driving cycle and modal emissions measured in the laboratory. This method was developed to reflect real-world motorcycle traffic conditions of Hanoi, Vietnam as well as to correspond to the economical - technical infrastructure of Vietnam.

Applying into the estimation of emission factors of four selected air pollutants of motorcycles including HC (hydrocarbons), CO (carbon monoxide), CO_2 (carbon dioxide) and NO_x (as NO), the following results were obtained: 1.109 (g/km), 11.355 (g/km), 43.971 (g/km) and 0.124 (g/km), respectively. These emission factors are a significant contribution to Vietnam database of emission factors that are still scarce. Emission factors obtained in this study would also help improve the accuracy of emission models and emission inventories, which plays an important role in air quality management and traffic planning of Hanoi, Vietnam.

1. INTRODUCTION

According to National State of Environment 2007, the transport sector is estimated to emit around 85% CO and 95% VOCs into the air of urban areas. Hanoi, with 1.8 millions motorcycles (until June 2007), is now facing with serious air pollution problem [1]. Estimating emission factors of vehicles to calculate total emissions and to serve emission inventories, has great significance for air quality management.

In developed countries, by fully worked-out data system of traffic conditions as well as vehicular types, not only emission factors database, but also statistics about vehicles, has been developed completely through main methods such as: totaling up the numbers of vehicles and experimenting with specific types of vehicles on test beds following given driving cycles; building emission models; or on-road data-based measuring…

However, emission factors for vehicles including motorcycles are still scarce in Vietnam while the need for doing emission inventories is increasing. Therefore, in an effort to initiate emission inventories for motorcycles in Hanoi, experts have to refer emission factors from other countries (e.g. from US. EPA). This may lead to incorrect results as referred data may not be corresponding to the traffic conditions of Hanoi. In this context, a set of emission factors for motorcycles which is based on the real-world traffic conditions of the city is needed. This study is, therefore, designed to meet that purpose. Due to the constraint of time and funding, the study is limited to the old area of Hanoi (before expanding on August 1st 2008). It also focuses on estimating emission factors of four selected air pollutants of motorcycles: HC (hydrocarbons), CO (carbon monoxide), CO_2 (carbon dioxide) and NOx (nitrogen oxides).

2. EMISSION FACTORS AND APPROACHES TO ESTIMATING VEHICULAR EMISSION FACTORS

2.1. Concept

According to USEPA: An emission factor is a tool that is used to estimate air pollution emissions to the atmosphere. It relates the quantity of pollutants released from a source to some activity associated with those emissions. Emission factors are usually expressed as the weight of pollutant emitted divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. In most cases, these emission factors are simply averages of available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category [2]. Especially for motorcycles (and other mechanical vehicles), emission factors are expressed as grams of pollutant per traveling kilometer or grams of pollutant per liter fuel consumed.

2.2. Methods used to estimate vehicular emission factors [3]

• Fuel-based models: Emission factors are normalized to fuel consumption and expressed as grams of pollutant per gallon of gasoline burned instead of grams of pollutant per mile. In order to obtain an overall fleet-average emission factor, average emission factors for subgroups of vehicles are weighted by the fraction of total fuel used by each vehicle subgroup. The fleet-average emission factor is multiplied by regional fuel sales to compute pollutant emissions.

• Modal emissions-based models: In order to estimate effects associated with driving dynamics the modal operation of a vehicle and related emissions need to be analyzed. Modal emissions-based models relate emissions directly to the operating mode of vehicles. The operating modes include cruise, acceleration, deceleration, and idle.

• Driving cycle-based models: A driving cycles is composed of a unique profile of stops, starts, constant speed cruises, accelerations and decelerations and is typically characterized by an overall time-weighted average speed. Different driving cycles are used to represent driving under different conditions. Driving cycle test data are used as the basis for estimating emission factors in these models.

• On-road data-based measurements: On-road emissions data can be obtained by using Remote Sensing Device (RSD) or on-board instrumentation. RSD uses infrared and, in some cases, ultraviolet spectroscopy to measure the concentrations of pollutants in exhausts emissions as the vehicle passes a sensor on the roadway. The major advantage of remote sensing is that it is possible to measure a large number of on-road vehicles. The major disadvantages of remote sensing are that it only gives an instantaneous estimate of emissions at a specific location, and cannot be used across multiple lanes of heavy traffic. Furthermore, remote sensing is more or less a fair weather technology.

3. METHODOLOGY

During conducting research, there are some advantages about materials and technical facilities:

- Thanks to the Laboratory of Internal Combustion Engine Laboratory - Hanoi University of Technology, all emission measurements were successfully conducted.
- The research on “Development of a local real-world driving cycle for motorcycles for Hanoi (HMDC driving cycle) and pilot emission factors for motorcycles” has contributed the

actual on-road time-speed data and the HMDC driving cycle. These were important bases for this research.

The following methodology was proposed as a result of analyzing the 4 approaches mentioned above as well as taking care of the current situation of availability of the emission data. The methodology was named as estimating emission factors based on driving cycles and modal emissions, which includes following steps (Figure 1):

- Conduct instantaneous emission measurements on chassis dynamometer,
- Analyze instantaneous emissions to develop correlation between emission rate and engine power,
- Collect time-speed data in the real driving condition that are used then for calculation of engine power,
- Estimate on-road emission factors for each driving trip,
- Develop emission factors.

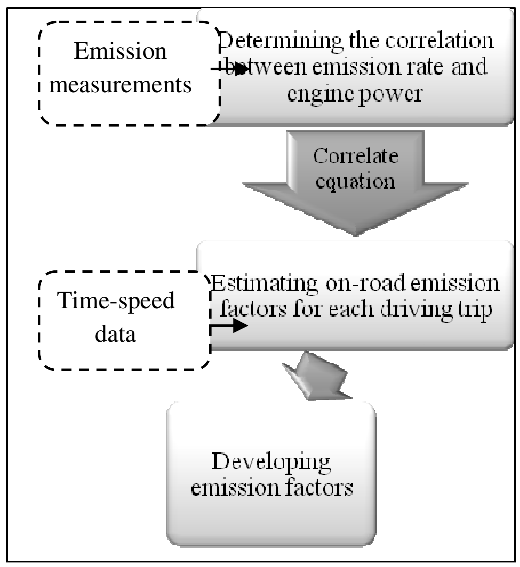

Figure 1. Steps to estimate emission factors

3.1. Determining the correlation between emission rate and engine power

Emission measurements on chassis dynamometer were conducted as follows:

- 5 selected motorcycles: Yamaha Jupiter MX, Yamaha Nouvo, Honda Wave RS, Honda Wave RSX, Honda Super Dream and SYM Attila Victoria.
- 2 driving cycles: ECE R40 European driving cycle (according to Vietnamese Standards TCVN 7357:2003) and HMDC real world driving cycle for Hanoi.

During experiments, exhaust gases were sampled by CVS system. Exhaust emissions were analyzed instantaneously with 1Hz frequent and from the bags by CEBII emission bench. Results of each measurement include parameters of HC, CO, CO_2 and NO_x. Together with emission measurement, speed, temperature, humidity, engine power, and fuel consumption were also continuously measured in every second. Among these parameters, engine power is considered to be the factor that influences mostly to emission rates. Therefore, this research focuses on the correlation between engine power and emission rates.

The driving behavior is divided into 4 driving modes: idle, acceleration, deceleration and cruise. The instantaneous measured emissions show that following these driving modes, the emission rate of each parameter behaves differently. As a result, data of each experiment were divided into 2 phases:

- Power (+) phase: with the positive acceleration ($a \geq 0$ m/s^2), corresponding to state of acceleration, cruise and idling.
- Power (-) phase: with the negative acceleration ($a < 0$ m/s^2), corresponding to state of deceleration.

The signals of engine power in percent from measured results were equally divided into 20 groups. While the signal of emission rates in mg/s correlative with power signal were averaged and also put into the corresponding groups.

From the graph of emission rate and engine power, a linear correlation between these parameters was formed as the below equation.

$$y = ax + b \tag{1}$$

where: y - Emission rates (mg/s; x - Engine power (%).

This is the basis for computing emission rate at any moment by engine power calculated from real world time-speed data.

3.2. Estimating on-road emission factors for each driving trip

Using on-road time-speed data obtained from driving trips measured on 10 representative streets in Hanoi [4] to calculate engine power by the formula [5]:

$$P = m*\{V*[1.1*A + 9.81*(atan(sin(G))) + 0.132] + 0.000302*V^3\} \tag{2}$$

where: P - Engine power (kW); V - Vehicle speed (m/s); A - Acceleration (m/s^2); m - Vehicle mass (tonne); G - Road grade in radians.

According to the on-road time-speed data, the road grade was not taken into account. Thus, in this study, this parameter was considered as zero (G = 0).

Using equation (1) and engine power obtained by (2), emission rates (ER) in each second were calculated. The emission factors for each driving trip (EF_i) were calculated by the following formula:

$$EF_i = \frac{\sum_1^k ER_j}{\sum_1^k s_j} \times 10^{-3} \tag{3}$$

where: EF_i,: Emission factors calculated from driving trip i, (g/km); ER_j: Emission rate at second j, (mg/s); k: Length of the driving trip, (s); s_j: Length of the road traveled in each second, (km/s).

3.3. Developing emission factors

Emission factor for each parameter is an average of all calculated emission factors obtained from equation (3).

$$EF = \frac{\sum_1^n EF_i}{n} \tag{4}$$

where: EF - Emission factor of HC, CO, CO_2 and NO_x (g/km); n - number of driving trips.

4. RESULTS AND DISCUSSION

4.1. Correlation between emission rate and engine power

Results of 16 instantaneous emission measurements were analyzed to have the correlation between emission rate and engine power giving in Figure 2 for power (+) phase.

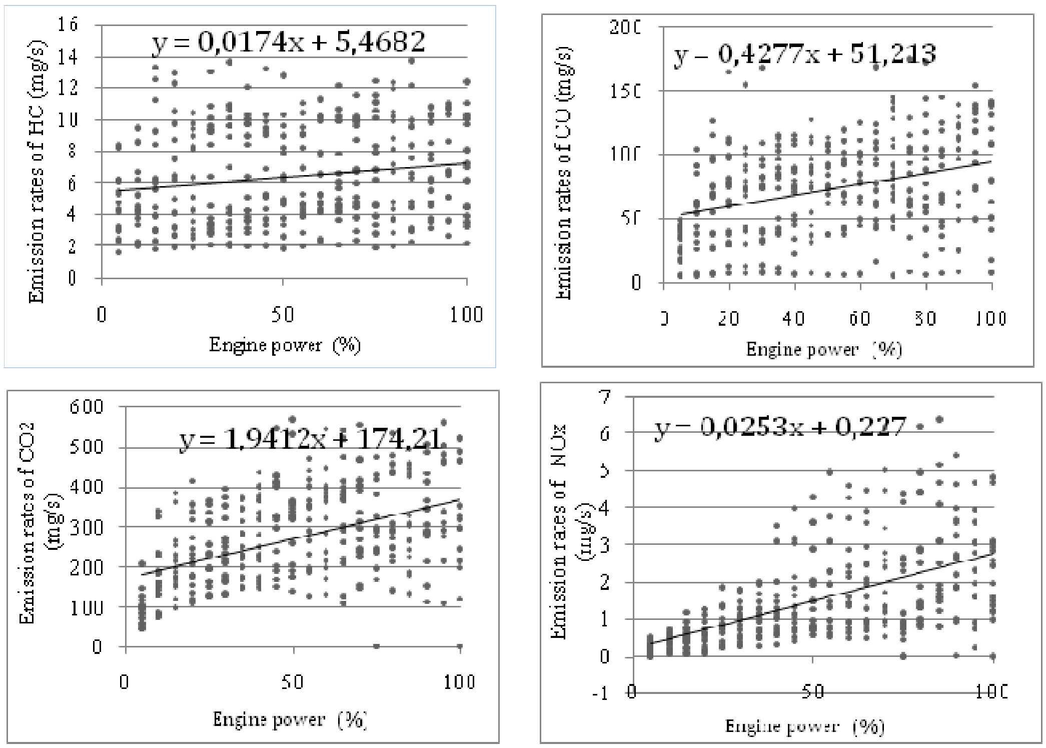

Figure 2. Correlations between engine power (+) phase and emission rates HC, CO, CO_2 and NO_x

The correlation functions between emission rates of HC, CO, CO2 and NOx and engine power are described as follows:

HC: $y = 0.0174x + 5.468$ (5)

CO: $y = 0.4277x + 51.213$ (6)

CO_2: $y = 1.9412x + 174.210$ (7)

NO_x: $y = 0.0253x + 0.227$ (8)

It can be seen from Figure 2 that, emission rates of CO and CO_2 are more dependent on the engine power than those of HC and NO_x as angular coefficients of the equations for CO and CO_2 are higher than those for HC and NO_x.

Similarly to the case of power (+) phase, the correlation between emission rates and engine power in the power (-) phase was established. Coefficients of the equation (1) for each selected parameter are given in Table 1.

Table 1. Coefficients of equation (1) in the power (-) phase

Parameter	a	b
HC	0.0064	5.0196
CO	0.1530	50.4600
CO_2	-0.0840	224.1000
NO_x	0.0010	0.1870

Unlike the power (+) phase, in the power (-) phase, the emission rates of all parameters can be considered not to be dependent on the engine power. This is a good estimation because, in reality, when decelerating, the effective engine power is nearly zero, the power generated by burning fuel is used only for overcoming the friction losses.

4.2. Developing real-world emission factors

Emission factors of parameters, EF_i, were calculated by using Formula 2 and Formulas from 5 to 8 for the power (+) phase, and by Formula 1 and Table 1 for the power (-) phase. Results of emission factors for three measurement times of a day, morning rush hour (7h30 – 8h30), office hour (9h00 – 11h00) and afternoon rush hour (17h00 – 18h00), for all parameters, are showed in Table 2.

Table 2. Emission factors of 10 routes, 3 measurements per day

Routes	Times of day	HC (g/km)	CO (g/km)	CO_2 (g/km)	NO_x (as NO) (g/km)
1	Afternoon rush hour	1.429	15.094	58.382	0.211
	Office hour	1.403	14.658	59.060	0.192
	Morning rush hour	1.081	11.275	44.713	0.137
2	Afternoon rush hour	1.468	15.508	60.251	0.210
	Office hour	1.473	15.638	61.747	0.219
	Morning rush hour	1.118	11.690	46.440	0.152
3	Afternoon rush hour	1.146	11.815	46.293	0.134
	Office hour	1.116	11.338	44.416	0.120
	Morning rush hour	1.044	10.419	41.106	0.095
4	Afternoon rush hour	1.197	12.414	48.629	0.150
	Office hour	1.079	11.274	43.966	0.142
	Morning rush hour	1.052	10.913	42.750	0.132
Routes	Times of day	HC (g/km)	CO (g/km)	CO_2 (g/km)	NO_x (as NO) (g/km)
5	Afternoon rush hour	1.194	12.039	46.088	0.115

	Office hour	0.810	8.426	32.127	0.105
	Morning rush hour	1.127	11.426	43.280	0.117
6	Afternoon rush hour	1.241	12.840	49.705	0.155
	Office hour	1.138	11.854	46.104	0.147
	Morning rush hour	1.553	15.514	61.303	0.134
7	Afternoon rush hour	1.087	11.329	44.206	0.139
	Office hour	1.180	12.248	46.984	0.149
	Morning rush hour	1.117	11.323	43.036	0.116
8	Afternoon rush hour	0.661	6.456	23.741	0.044
	Office hour	0.649	6.327	23.309	0.042
	Morning rush hour	0.606	5.981	22.617	0.043
9	Afternoon rush hour	1.637	15.765	58.324	0.082
	Office hour	1.150	11.705	45.116	0.121
	Morning rush hour	1.065	10.652	40.651	0.091
10	Afternoon rush hour	0.890	9.196	35.739	0.109
	Office hour	0.819	8.272	31.582	0.078
	Morning rush hour	0.739	7.261	27.465	0.050

It can be seen from Table 2 that, with each parameter, there may be a fluctuation on emission factors from three measurements of a day. However, the dominant tendency is that the emission factors in the afternoon rush hours are higher than those in other hours, which is considered to be agreed with the real traffic conditions of Hanoi (vehicles density is highest during afternoon rush hours).

Among 10 representative streets (Hang Da - Hang Dieu - Hang Ga - Hang Cot, Hang Giay - Hang Duong - Hang Ngang - Hang Dao, Pho Hue - Hang Bai, Tran Hung Dao, Kim Ma, Nguyen Thai Hoc, Tay Son - Nguyen Luong Bang - Ton Duc Thang, Pham Hung, Truong Chinh and Giai Phong), the results of EF_i on two streets, namely Pham Hung (No.8) and Giai Phong (No.10), were lower than those on the others as given in Table 3.

In reality, these 2 streets (Pham Hung and Giai Phong) have a small number of stops and high average vehicle speed. Consequently, motorcycle emissions on these streets are lower. This needs to be taken into account during long-term planning for traffic flow separation in order to minimize the emissions. Values in Table 2 can be considered as specific emission factors for these considered streets.

Table 3. Emission factors per route

Routes	HC (g/km)	CO (g/km)	CO2 (g/km)	NOx (as NO) (g/km)

1	1.304	13.676	54.052	0.180
2	1.353	14.278	56.146	0.194
3	1.102	11.191	43.938	0.117
4	1.109	11.533	45.115	0.141
5	1.044	10.630	40.498	0.112
6	1.311	13.403	52.371	0.145
7	1.128	11.633	44.742	0.135
8	0.638	6.255	23.222	0.043
9	1.284	12.708	48.030	0.098
10	0.816	8.243	31.595	0.079

4.3. Developing emission factors

Following Formula 4, emission factors for motorcycles were estimated and given in Table 3.

Table 4. Emission factors

Parameters	HC	CO	CO_2	NO_x (as NO)
Unit	g/km	g/km	g/km	g/km
Emission factors	1.109	11.355	43.971	0.124

Comparisons of these emission factors with EURO II emission standards are presented in Figures 3 and 4.

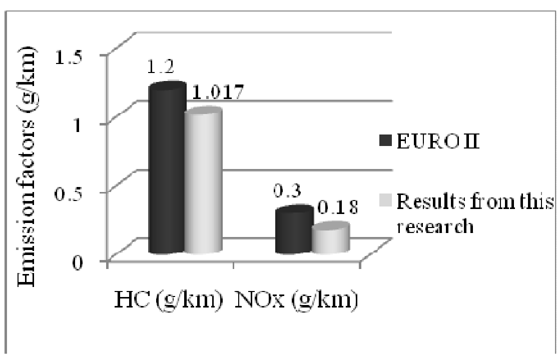

Figure 3. Emission factors of HC and NOx in the comparison with EURO II limits

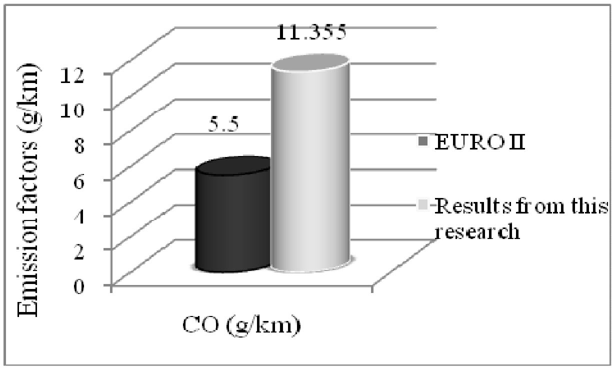

Figure 4. Emission factors of CO in the comparison with EURO II limit

It can be seen from Figures 3 and 4 that emission factors of HC and NO_x are lower than EURO II limits, while emission factor of CO is about 2 times higher than EURO II limit.

In addition, emission factor of CO_2 obtained in this study is found to be in the same range with that estimated by EMBARQ (see Figure 5) which was estimated based on carbon-balance method [6].

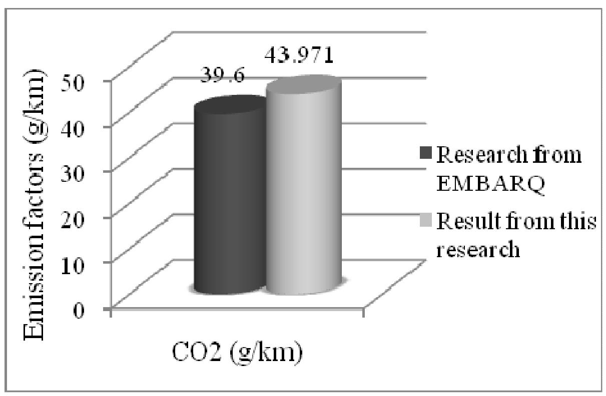

Figure 5. Emission factor of CO2 in this study and results from EMBARQ research

5. CONCLUSION

The methodology developed by this study is practical and suitable for Vietnam to develop real world emission factors. This methodology can be used to estimate emission factors not only for motorcycles but also for other vehicles such as cars, lorries, buses etc. Correlation functions between the engine power and the emission obtained could be used to estimate emission factors of any route, based on time-speed data of the route. Emission factors obtained in this study can be used directly in estimating total emissions from motorcycles in Hanoi, which help bring a real picture of current emissions as well as emission scenarios of motorcycles for the future. These emission factors can also be applied to conduct emission inventories for motorcycles in Hanoi.

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TÓM TẮT

BƯỚC ĐẦU ƯỚC TÍNH HỆ SỐ PHÁT THẢI CHO XE MÁY
ỨNG VỚI ĐIỀU KIỆN GIAO THÔNG THỰC TẾ Ở HÀ NỘI

Bài báo trình bày phương pháp luận để ước tính hệ số phát thải cho xe máy dựa trên chu trình lái đặc trưng và phương thức phát thải của phương tiện được đo đạc trong phòng thí nghiệm. Phương pháp này được phát triển nhằm phản ánh tình hình giao thông thực tế của xe máy tại Hà Nội và phù hợp với điều kiện kinh tế - kỹ thuật của Việt Nam.

Áp dụng phương pháp này vào việc xác định hệ số phát thải cho bốn chất ô nhiễm chính của xe máy là HC (hydrocacbon), CO (cacbon monoxit), CO_2 (cacbon dioxit) và NO_x (tính theo NO) cho kết quả tương ứng là 1,109 (g/km), 11,355 (g/km), 43,971 (g/km) và 0,124 (g/km). Kết quả này là một đóng góp đáng kể cho cơ sở dữ kiệu về hệ số phát thải của Việt Nam, hiện còn rất nghèo nàn. Hệ số phát thải thu được trong nghiên cứu này cũng giúp nâng cao tính chính xác của mô hình phát thải và kiểm kê phát thải – là những công cụ rất quan trọng trong công tác quản lí chất lượng không khí và quy hoạch giao thông của Thủ đô Hà Nội.

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