VNU Journal of Science, Earth Sciences 24 (2008) 184-192

Estimation of emission factors of air pollutants from the road traffic in Ho Chi Minh City

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Received 24 December 2008; received in revised form 27 January 2009.

Abstract. The estimation of emissions largely depends on the quality of emission factors used for calculation. The study on the estimation of emission factors is important for calculating the emission of air pollutants from road traffic in Ho Chi Minh City (HCMC).

The result of this study is the selection of a suitable method and tracer for estimating emission factors of 15 volatile organic compounds (VOCs) from C_2-C_6 and NO_x from road traffic in HCMC. The survey has been carried out in 3/2 Street, District 10, HCMC from January to March 2007.

Three VOCs compounds with high average emission factors are hexane (59,7 ± 9,2 mg/km.veh.), iso-pentane (52,7 ± 7,4 mg/km.veh.) and 3-methylpentane (36,1 ± 3,6 mg/km.veh.) and the average emission factor of NO_x is 0,20 ± 0,03 g/km.veh. Besides, the emission factors of air pollutants for motorcycles, light-duty vehicles and heavy-duty vehicles are calculated by using the linear regression method.

Keywords: Emission factors; Tracer; VOCs; NO_x.

1. Introduction

The increasing number of vehicles in HCMC leads to the increase of harmful emissions, as well as the concentration of air pollutants. The calculation of air pollution emission by road traffic for simulating the distribution process of air pollutants is of very importance for environmental management. Therefore, the study on determining the emission factors to calculate emission of air pollutants from the road traffic in HCMC is necessary so far.

There are two approaches to determine the emission factors by road traffic: the traditional approach (bottom up) - directly measurement of exhaust gas from each type of vehicle by dynamometer; and the alternative approach (top down) - determining the emission factors based on real-world traffic conditions.

Dynamometer tests are an essential part of the methodology required for drafting vehicle emission [3, 17]. However, dynamometer tests can not accurately reflect the importance of factors present in on-road situations, such as actual driving conditions and evaporative emissions from fuel tanks. Besides, dynamometer tests are time consuming, costly, and the number of testable vehicles in most studies is limited.

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In recent years, a new approach has been developed. This approach is based on the indirect estimation of emission factors under real-world conditions. Different methodologies can be considered as top down techniques including the tunnel studies and the inverse application of air quality models at microscale level. A number of studies on real-world road traffic emission factors have been done in road tunnels (e.g. Staehelin et al. [15]; Kristensson et al. [10]; Hung-Lung et al. [5]; Hwa et al. [6]). The advantage of road tunnel studies is the low cost, and possibility of determining emissions not only from the engines, but also from evaporation of fuel. However, it is not always possible to find a tunnel close or inside the city were the emissions are produced and which would represent in a better way the real-world urban conditions, the classification of vehicle types is not in detail and only allows us to calculate emission factors in some limited ranges of vehicle speeds.

Another of top down approach is the inverse application of an air quality model (also called inverse modeling), has been applied for the first time by Palmgren et al. [13]. This method describes theoretically the relationship between emissions, dispersion of air pollutants and resulting air pollutant concentrations.

The inverse modeling has been used to estimate the emission factors in different cities of the world [2, 8, 9, 13]. The advantage of this technique is that it is possible to estimate the emissions under real-world conditions. On the other hand, since the method uses an air quality model to estimate the dispersion function, the accuracy of the estimated emissions will depend on the ability of the model to reproduce the dispersion of the pollutants.

Until now, in Vietnam in general and HCMC in particular, the study on determining the emission factors by road traffic have been initially interested by scientists and environmental managers. However, due to the inappropriateness of research method and the lack of research facilities, until now it has not been implemented, particularly with the method used tracer experiment to determine the emission factors by road traffic.

2. Selection of method for estimating emission factors

Based on the analysis of advantages and disadvantages of the currently available methods, it shows that the inverse air quality model method is more suitable for the conditions of HCMC.

The relationship between air pollutant concentration (*C*), emission of the pollutant (*E*) and dispersion, dilution factor (*F*) from road traffic is expressed in the basic equation:

$$C = F(model).E + C_{background}, \qquad (1)$$

in which, C is the concentration of a particular pollutant in the street (g/m^3 or mg/m^3); E is the emission of the pollutant from road traffic in the street; F is a function describing the dispersion, dilution processes, it depends mainly on meteorological parameters such as wind speed and wind direction above the roof; and $C_{background}$ is the contribution to pollutant concentrations in street from all other sources.

In this study, we determine the dispersion, dilution factor F by using tracer experiment with measurement of meteorological parameters to determine the emissions of air pollutants based on the measurement of their concentrations at the same time with tracer experiment. The factor F is determined base on the equation:

$$F_h = \frac{C_h - C_{h,background}}{E_h} \qquad (2)$$

For a specific hour, h, the average emission factors of vehicle and the emission factors for motorcycles (MC), light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) can be expressed as:

$$E_h = e_f \times n = \sum_k N_{k,h} \times q_k , \qquad (3)$$

in which, e_f is the average emission factor of vehicles (g/km/veh.); n is total vehicle number; $N_{k,h}$ and q_k are the traffic flow and emission factor for the k_h vehicle category, respectively.

3. Experimental set up

3.1. Design of the experiment system

Experiment system includes two main parts: the tracer liberation system and equipments for measuring pollutants and tracer concentration. Two parts are put at opposite kerb-sides at the experiment site.

A simple box model from Olcese L. E. [11] is used to calculate the tracer emission rate needed. The calculation shows that a continuous propane emission rate of 0.21 m^3/h (0.38 kg/h) is enough to reach a propane concentration at street level of about 150 ppb. Since there is 39.1% of propane in LPG, the amount of LPG needed is 0.54 m^3/h (or 9 l/min).

3.2. Experiment site selection

Experiment site is selected based on the following criteria: with all kind of vehicles, the high buildings surrounding the street are not very different; avoid the influence of industrial and living activities.

The selected experiment site is located on the 3/2 Street, District 10, HCMC, in front of the Marximark supermarket. The traffic volume in this area is very high with 325,000 veh./day in average and there are often traffic jams in rush hours with the traffic volume of 24,000 veh./hour.

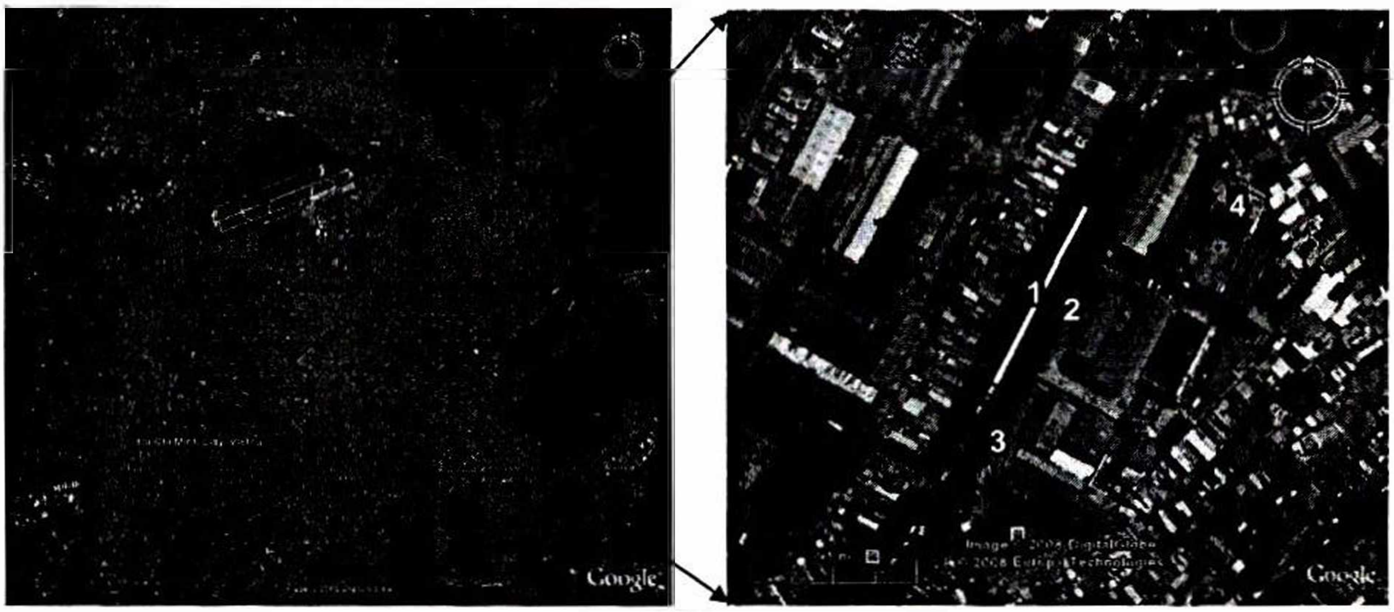

Fig. 1. The survey site (left: in HCMC map; right: in 3/2 Street, 1: Emission liberation device; 2: Mobile station; 3: Traffic video recording; 4: Weather station).

3.3. Selection of tracer

In the world, tracer is widely used for many research purposes: (a) investigate the ability to model the air pollution dispersion process in an urban area; (b) evaluate long-range transport atmospheric dispersion models in general; (c) verify a two dimensional air quality numerical model in an urban street canyon; (d) determine the ventilation flux inside road tunnels.

Based on the requirements and combined with the real conditions in HCMC, tracer selected for research is propane with the reasons that propane is a non-reactive gas, easily available, it is much cheaper, easy to detect with commercial on-line gas chromatographs, negligible global warming potential (GWP) and ozone depleting potential (OPD).

3.4. Experiments

a. Measurement of air pollutants

The air pollutants were measured by standard automatic devices from S.A Environment, France: Module AC 31M monitor NO_x ($NO+NO_2$), module MP 101M monitor $PM_{2.5}$ and GC955 with FID and PID monitor VOCs (C_2-C_6). All equipments were calibrated every week with standard mix gas.

b. Tracer experiment

The tracer liberation system consists of two parts. The first part is a tracer emission device, and the second part is an online gas chromatograph used to measure the resulting tracer concentrations.

c. Weather information

The registered meteorological parameters are: wind speed, wind direction, temperature, humidity, UV, solar radiation, rain, atmospheric pressure were measured by weather station. This equiment was placed on the top of the building No.3, 3/2 Str., Dist. 10, which is located close to the measuring site (see Fig. 1).

d. Vehicle information

Traffic flow is continuously recorded by a video camera (see Fig. 1). Traffic volumes are counted manually after the measuring campaign. The vehicles are classified into three different groups: light-duty vehicles (LDVs) such as gasoline light-duty passenger vehicles and light-duty trucks (under approximately 1 ton gross weight); heavy-duty vehicles (HDVs) such as diesel trucks (above approximately 1 ton gross weight) and buses; and gasoline motorcycles (MC).

4. Results and discussion

4.1. Vehicle information

The statistics show that most of vehicles are MC, and their contribution ranges from 91.3% to 97.3% (average: 94.6%), the contribution of LDVs ranged from 2.1% to 6.5% (average: 4.2%), and the contribution of HDVs ranged from 0.2% to 2.7% (average: 2.0%). The speed of vehicles is changed during the day. The average speed of motorcycles is 40.5 km/h; cars - 42.4 km/h; light trucks - 41.8 km/h; heavy trucks - 35.7 km/h; and buses - 39.7 km/h.

4.2. Air pollutant concentration

The most abundant VOCs in this research were hexane, iso-pentane and 3-methylpentane. These three species account nearly to 60% of the total VOCs measured. The mean concentration of benzene registered in the 3/2 Street exceeds the Vietnamese standard TCVN 5938:2005 (hourly average 22 $\mu g/m^3$) with the factor 2.1. The mean NO_2 concentration lower than the Vietnamese standard TCVN 5937:2005 (hourly average 200 $\mu g/m^3$), but sometimes the NO_2 concentration exceeds the standard.

4.3. Tracer concentration

The average propane concentration during the liberation is well above the typical propane concentration present in the place. Several factors are related to the dispersion of pollutants in a street canyon. The main factors are the street and buildings geometry, the prevalent wind speed and wind directions, and, to some extent, the traffic induced turbulence.

From 10 am to 2 pm, the wind blows to different directions and lower wind conditions prevail. The lowest tracer concentrations are observed at this period of the day. From 2 pm to 6 pm, the wind direction is oblique to the street axis and the wind speed is higher than in the morning. At these hours of the day, tracer concentrations are higher than that in the morning. From 6 pm to 10 pm, the wind direction is nearly perpendicular to the street axis and the wind speed is also high. Tracer concentrations from 6 pm to 10 pm are the highest observed. Different analysis measurement studies have shown that at high wind speeds and when the wind is perpendicular to the street axis, the concentration of pollutants increases at the leeward side of the street.

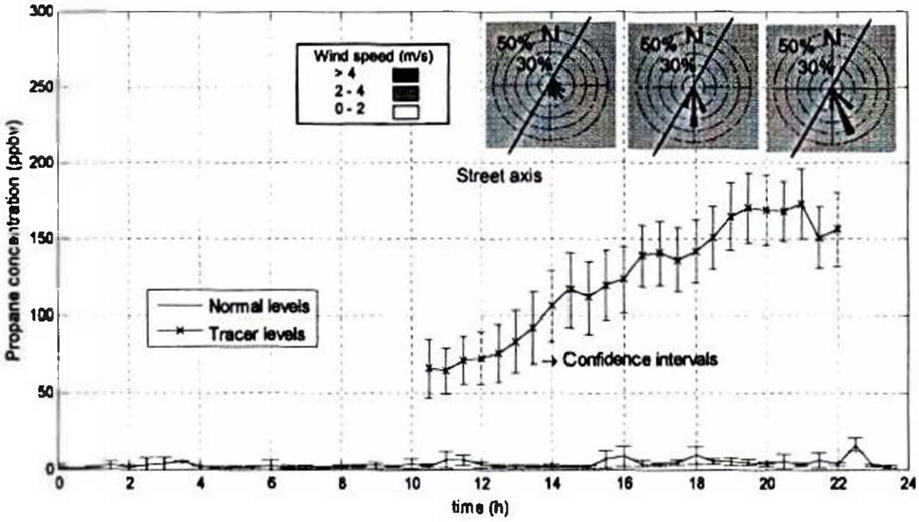

Fig. 2. Propane concentration in normal level and during tracer experiment.

4.4. Identification of air pollutant sources

Principal Component Analysis (PCA) tool of SPSS (Statistical Product and Service Solutions) - a powerful computer program with wide variety of statistical analysis - software version 15.0 was applied to identify the air pollutant sources. The obtained results are shown in Table 1. Some remarks can be made as follows:

The factor No 1 (F1) has high loadings for all of the VOCs except isoprene. VOCs like isopentane, n-pentane and benzene have been associated to gasoline vehicle emissions and gasoline evaporation. Besides, NO also has a high loading in F1, attributed to diesel powered vehicle emissions, then, F1 corresponds to the vehicle emissions.

Factor number 2 (F2) has a high loading for isoprene. Isoprene is associated to biogenic sources, this VOC is also attributed to the road traffic. Besides, $PM_{2.5}$ and NO_2 are also associated to F2. NO_2 is mainly associated to chemical production, fine particles in HCMC have been attributed to other sources than traffic [7]. This PCA analysis confirms that the road traffic is not an important source of $PM_{2.5}$. Therefore, F2 is a group of the following sources: biogenic, chemical production and other sources.

Table 1. PCA results for air pollutants

No.	Compound	Factors	
		F1	F2
1	Propene	0.960	
2	Trans-2-butene	0.961	
3	1-butene	0.980	
4	Cis-2-butene	0.785	
5	Iso-pentane	0.970	
6	n-pentane	0.956	
7	1,3 butadiene	0.961	
8	Trans-2-pentene	0.954	
9	1-pentene	0.968	
10	2-methyl-2-butene	0.963	
11	Cis-2-pentence	0.978	
12	2,3-dimethylbutane	0.947	
13	2-methylpentane	0.858	
14	3-methylpentane	0.979	
15	Hexane	0.934	
16	Isoprene		0.635
17	Benzene	0.911	
18	$PM_{2.5}$		-0.764
19	NO	0.537	
20	NO_2		-0.636

4.5. Estimation of traffic emission factors

4.5.1. Total emission factors for all vehicles

a. Estimation total emission factors

Total emission of pollutant was calculated by using Eq. 1, where the dispersion, dilution factor (F) is estimated by tracer experiment:

$$F_i = C_{t,i} / E_t - C_{t,i\ background} \quad (4)$$

Since $C_{t,i\ background}$ is many times lower than $C_{t,i}$, we can neglect $C_{t,i\ background}$ in Eq. 4; $C_{t,i}$ is the concentration of tracer measured at time i, E_t=1.912.582 mg/km½; h is the propane emission rate along 100 m hose during 30 minutes. Replacing E_h from Eq. 3 into Eq. 1, one can obtain:

$$C_i = F_i.n.e_f + C_{i,\ bachground} \quad (5)$$

In the above equation, C_i is the concentration of pollutant; n is the total number of of vehicles at time i, e_f is the average emission factor (mg/km.veh) and $C_{i,\ background}$ is the background concentration of pollutant at time i.

The slope of linear regression graph of the $n.F_i$ vs C_i plot may correspond to the emission factor e_f (mg/km.veh) for that specific pollutant. The dispersion factor F_i is independent on the pollutant type and it can be used to calculate the emission rates for any pollutant monitored. $C_{background}$ of air pollutants can also be estimated from that equation.

The three VOCs with high average emission factors were n-hexane, iso-pentane, and 3-methylpentane. The average emission factors of $NO_x(NO)$ is 0,20 ± 0,03 g/km.veh.

b. Comparison with other studies

Comparison of the average emission factors of VOCs in this study with some other studies in Japan [8], Taiwan [5, 6], Korea [12], and France [16] expressed in Table 2 showed that there are almost no difference between the emission factors of VOCs obtained in this study and that in Taiwan, only the emission factors of 3-methylpentane and hexane were higher with the factors from 6 to 8 times. The difference with the study in Korea is not so much. Emission factors of iso-pentane, 3 methylpentane, hexane were higher with the factors from 2 - 4 times. However, the emission factor of trans-2-butene, cis-2-butene, benzene, etc were lower. The comparison with the study results in France shows that the emission factor of propene and iso-pentane in HCMC is higher. Conversely, the emission factors of 3-methylpentane and hexane were lower. The coincides with all studies that the value of emission factor of iso-pentane is highest in all VOCs from C_2-C_6. Thus, it can be said gasoline is the fuel commonly used in the world.

Table 2. The average emission factors of VOCs and NO_x (mg/km.veh)

Compound	e_f	CI (%)	C_b (ppb)	C (ppb)	Study (1)	Study (2)	Study (3)	Study (4)	Study (5)
Propene	19.8	9	19.1	29.5	-	11.61	-	61.2	10.36
Trans-2-Butene	3.8	17	6.0	7.9	-	1.61	10.4	7.7	0.81
1-Butene	3.8	11	4.3	6.3	-	8.27	19.3	10.7	10.67
Cis-2-butene	3.6	17	5.7	7.5	-	1.84	6.3	5.7	1.56
iso-pentane	52.7	14	97.2	122.9	11.0	12.50	21.9	153.0	40.07
n-Pentane	16.4	11	25.8	33.7	5.0	9.52	19.6	12.6	19.28
Trans-2-Pentene	9.9	15	18.9	23.8	-	2.76	1.2	6.5	4.08
1-Pentene	3.5	12	4.3	5.9	-	1.61	3.0	3.3	0.97
2-methyl-2-butene	2.6	14	4.4	5.6	-	-	-	-	-
Cis-2-Pentene	3.3	12	4.0	5.6	-	1.59	6.7	3.4	1.57
2,3-Dimethylbutane	7.7	11	9.5	13.6	-	1.33	15.1	-	12.70
2-Methylpentane	7.3	12	9.1	12.8	-	5.27	18.6	15.4	12.56
3-Methylpentane	36.1	10	47.5	65.6	5.9	6.39	19.1	9.1	5.62
n-Hexane	59.7	16	106.2	136.5	-	4.18	13.0	5.5	5.70
Benzene	10.7	13	14.9	20.4	5.2	12.21	20.6	-	5.87
NO_x (NO)	200.6	15	39.3	128.5	-	-	-	-	-

Note: CI: Confidence interval; C_b:Background concentration; C: Average concentration of air pollutants; (1)Kawashima H. et al., 2006 [8]; (2)Hwa M. Y.et al., 2002 [6]; (3)Na K. et al., 2002 [12]; (4)Touaty M. et al., 2000 [16]; (5)Hung-Lung C. et al., 2007 [5].

The comparison in Table 2 shows that the average emission factor of NOx in this study is lower than the result of researchers around the world. This can be explained by the differences in the rate of HDVs type (diesel vehicles) in the total number of vehicles, since NOx emitted from diesel vehicles is higher than that from gasoline vehicles. In the research in HCMC, HDVs contribute only about 0.5% of the total number of vehicles, while according to results of research Hung-Lung C. [5], the HDVs is about 15%. Similarly, in the research of Hwa Y. [6], the HDVs is about 7%, and John C. [7] - 12%.

4.5.2. Emission factors for MC, LDVs & HDVs

a. Calculation of emission factors

Emission factors of air pollutants for MC, LDVs and HDVs are determined by using the following equation:

$$E_{h,i} = e_f \times n = N_{MC} \times q_{MC,i} + N_{LDVs} \times q_{LDVs,i} + N_{HDVs} \times q_{HDVs,i} \quad (6)$$

in which, E_h is hourly average total emission of air pollutants; N_{MC}, N_{LDVs}, N_{HVDs} are traffic volumes for MC, LDVs, and HDVs; q_{MC}, q_{LDVs}, q_{HVDs} are emission factors of air pollutants for each type of vehicles; i is the time of estimating emission factors.

Eq. 6 is showed by linear regression method using SPSS 15.0 software. Emission factors of VOCs for MC in range 5,3 – 149,9 mg/km.veh., for LDVs in range 0,04 – 1,97 g/km.veh., and for HDVs in range 0,21 - 5,71 g/km.veh. In VOCs, the emission factors of iso-pentane is highest with 149,9 ± 46,4 mg/km.veh. for MC; 1,97 ± 0,61 g/km.veh. for LDVs and 5,71 ± 1,60 g/km.veh. for HDVs. In general, the emission factors of iso-pentane has a high value because iso-pentane is one of the VOCs emitted from engine and evaporation from fuel tank.

b. Comparison with other studies

Table 3. Comparison emission factors of NO_x with other studies (g/km.veh.)

No.	Author/research	MC	LDVs	HDVs	Note
1.	This study	0.43 ± 0.04	1.07 ± 0.23	17.38 ± 4.05	
2.	Tsai J. et al., 2000 [18]	0.46 ± 0.04	-	-	New
		0.25 ± 0.13	-	-	In use
3.	Tsai J. et al., 2003 [17]	0.15 ± 0.06	-	-	04 stroke - new
		0.18 ± 0.07	-	-	04 stroke
4.	John C. et al., 1999 [7]	-	1.05 ± 0.09	15.59 ± 0.79	-
5.	Kristensson A. et al., 1999 [10]	-	1.07 ± 0.03	8.0 ± 0.8	-
6.	Zarate E. et al., 2007 [19]	-	0.11 ± 0.02	18.9 ± 0.37	-

Comparison with the other studies in the world shows that the emission factors of NO_x for MC in this study is not different with the study in Taiwan [17, 18]. Similarly, the emission factors of NO_x for LDVs and HDVs also not so different with the results of study in Switzerland [7] and Columbia [19].

Comparison of results in this study with some studies in Japan [8], the United States [14] shows that there is a large difference in the emission factors of VOCs for LDVs and HDVs. The emission factors calculated in this study are generally higher compared to the results of the other studies around the world. Only the emission factor of VOCs for MC has a little difference with the results in Japan.

The difference of emission factors in this study and the other studies can be explained by the following reasons: the difference of components in the fuel types used; type and age of the engines; circulation conditions of vehicles; topography of the study area.

5. Conclusions

1. Based on the advantages and disadvantages of methods for determining emission factors combined with the real conditions of HCMC, the authors have used a new approach of inverse modeling air quality combination tracer experiment and measurement to identify emission factors of air pollution due to road traffic in HCMC. In this research, propane is chosen as the suitable tracer.

2. This is the first time that the measurement and experiment is implemented in Vietnam to calculate the emission factors of 15 VOCs from C_2 - C_6 and NO_x(NO) by road traffic in HCMC. The obtained results show that motorcycles have the average rate of 94.6%, light-duty vehicles - 4.2%, and heavy-duty vehicles - 1.2%.

Three VOCs which yield the highest average emission factors are n-hexane (59.7 ± 9.2 mg/km.veh.), iso-pentane (52.7 ± 7.4 mg/km.veh.) and 3-methylpentane (36.1 ± 3.6 mg/km.veh.), the average emission factor of NO_x(NO) is 0.20 ± 0.03 g/km.veh. Especially, in this study the authors has been estimated the emission factors of VOCs and NO_x(NO) from motorcycles, which are considered to be the most popular transportation vehicles in HCMC.

3. Comparison of the obtained results with other overseas studies shows that there is no difference on the average emission factors of VOCs, but the average emission factors of NO_x(NO) in this research is lower in comparison with other researches. However, the emission factors of VOCs for MC, LDVs and HDVs in this research is higher compared with other researches, but NO_x(NO) does not show a large difference. The reason of differences can be explained by different component types of fuel used, the ratio between the types of vehicles, type and age of the vehicle and topographical factors, etc.

5. The further research is to improve the methods for determining emission factors in HCMC in particular and Vietnam in general.

Acknowledgements

The authors are grateful to the ABC (Asia Brown Cloud) Project, which is the cooperation between Institute of Environment and Resources and Swiss Federal Institute of Technology (EPFL), for financial and technical support.

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