An alternative technique to estimate road traffic emission factors

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ABSTRACT

Road traffic emission factors (EFs) are one of the main sources of uncertainties in emission inventories; it is necessary to reduce these uncertainties to manage air quality more efficiently. In this work we present a new method to estimate road traffic emission factors (EFs). The method is based on a long term tracer experiment conducted in a busy street of Ho Chi Minh City (HCMC) – Vietnam. We emitted continuously a passive tracer from a finite line source placed on one site of the street. At the same time, we measured continuously the resulting tracer concentrations at the other side of the street with a portable on-line gas chromatograph. The results of the HCMC tracer experiment were used together with traffic counts and pollutant measurements to calculate the dispersion factors and afterwards the EFs. Results show that the estimated EFs for HCMC are within the range of EFs estimated in other studies. We also used a Computational Fluid Dynamics Model (CFD) to evaluate the proposed methodology. The evaluations show that it is possible to accurately estimate the EFs from tracer studies

The methodology presented in this work serve for different proposes and their use can provide useful information for the air quality assessment. For example, results from the tracer study can be used to estimate the EFs under real urban conditions; it can be also used to validate near road dispersion models which in turn can be used in the future to evaluate abatement strategies.

INTRODUCTION

Motor vehicles are one of the main sources of pollution in cities, however, emission inventories for this source of air pollutants show large uncertainties[1,2]. Road traffic emission factors (EFs) are one of the main sources of these uncertainties, in developed countries EFs for criteria pollutants are close to the real world emissions, but emission factors for Hazardous Air Pollutants (HAPs) like particle species or Volatile Organic Compound species (VOCs) are uncertain. On the other hand, in many cities from the developing world there are large uncertainties associated to EFs for criteria pollutants[3], and in most of the cases HAPs EFs are unknown.

There are different techniques to estimate EFs, the most used direct exhaust emission measurements are chassis dynamometer and on-board emission measurements. In a chassis dynamometer the EFs are estimated under standardized laboratory conditions, however this technique is cost expensive and only a limited number of vehicles can be evaluated, thus it is difficult to test a representative sample of vehicles[4]. The on-board emission technique estimates EFs under real urban conditions but the number of vehicles that can be tested is also limited.

There are alternative methods to estimate EFs. The most widely used are tunnel studies, inverse modeling and the use of criteria pollutants as tracers. Tunnel studies are an interesting alternative to

estimate emission factors but it is not always possible to find a tunnel close or inside a city where the emissions are released and which would represent in a better way the real-world urban conditions. The advantage of inverse modeling is that it is possible to estimate the emissions under real-world urban conditions. On the other hand, since the method uses an air quality model to estimate the EFs, the accuracy of the estimated EFs depends on the ability of the model to reproduce the dispersion of the pollutants. The tracer techniques uses a known EF of a criteria pollutant to estimate the dispersion at street level and after, it uses that dispersion and air quality measurements of HAPs or other criteria pollutants to estimate their EFs[5]. The advantage of this method is that it is possible to estimate EFs under real urban conditions and for a representative number of vehicles. However, the accuracy of the estimated EFs depends on the accuracy of the EF used to estimate the dispersion.

As can be seen, all the available methods offer advantages and also face limitations and thus, it is necessary to develop new methods to estimate more accurate EFs. In this work we present a new method to estimate EFs, A known amount of a passive tracer substance is continuously released, this passive tracer is used to quantify the dispersion and then the dispersion is used together with traffic counts and roadside pollutant measurements of other pollutants to estimate the EFs. Here EFs are estimated at real urban conditions and for a representative sample of vehicles. Moreover, since we know the amount of tracer released, the dispersion is more accurately estimated and then it reduces the uncertainties of the estimated EFs. In this work we also use a Computational Fluid Dynamics Model (CFD) to evaluate the proposed methodology.

METHODOLOGY

The EFs are estimated from a long term tracer study conducted in Ho Chi Minh City (HCMC), Vietnam. This experiment was developed in the Ba Thang Hai street, a very congested two-ways street located close to the centre of the city. In this street, as in HCMC, 95% of the fleet are motorcycles.

Figure 1. Set up of the tracer experiment in the Ba Thang Hai Street (HCMC).
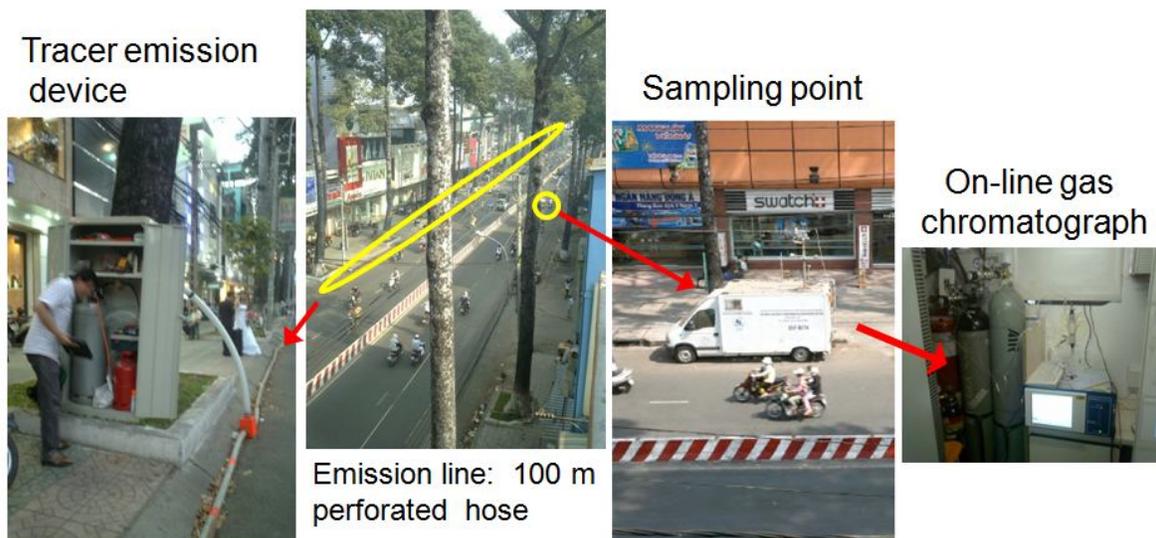
The tracer was released continuously from a 100 m perforated hose placed on one side of the BTH street (Figure 1). At the same time, the resulting tracer concentrations were measured on-line at the other side of the street with a portable on-line gas chromatograph. The tracer was emitted in the dry season (January-February 2007) from 10:00 to 22:00 during 25 days for a total of about 300 hours. Up to our

knowledge this is the longest tracer study reported to date. This was only possible due to the tracer selected and the experimental set up used.

Tracer selection and emission rate

The selection of the tracer is a crucial part for the development of a long term tracer study. The suitable substance should fulfill the next conditions:

- Non-toxic
- Negligible global warming potential (GWP) and ozone depletion potential (ODP)
- Cheap
- Stable and non-reactive
- Easy to measure on-line with commercial air quality monitoring equipment
- Low or negligible background concentrations in the urban air

CFCs, N_2O, and SF_6 have been used as passive tracer in different air quality studies. Despite the background concentrations of these compounds in the urban air is very low (< 1ppb), most of these substances are expensive. Besides, the available equipment to measure these substances on-line is very expensive. These substances also have large GWP and/or ODP.

After an exhaustive search for a suitable substance, and despite the fact that there is not a "perfect tracer", we concluded that *n-propane* is the best option for this kind of studies. Thus, we used n-propane contained in commercial Liquefied Petroleum Gas (LPG). LPG is non-toxic, cheap and easily available. Their molar composition in Vietnam is: n-propane: 39%; n-butane: 30%; i-butane: 30%; others: 1%.

N-propane fulfill all the conditions except that its background concentration ranges from 2 -20 ppb in the urban air. Nevertheless, since this compound is non-toxic and very cheap, it is possible to emit larger amounts of this substance in a way that their resulting concentrations are well above this background. Preliminary measurements in the measurement site showed that the background concentration of n-propane was in average 4 ppb. We used a simple box model to determine the n-propane emission rate needed to be well above this background. The results showed that the emission rate needed is 0.105 g of propane per second. This emission rate produces roadside concentrations which are between 10 and 40 times above the typical propane concentrations in the measurement site; see more details at[7].

Another limitation of n-propane is that it is a flammable substance and then it may represent a potential risk in the street. To overcome this limitation we diluted the LPG with enough air to be below the Lower Explosion Limit (LEL) of LPG (2%). We used an industrial blower to produce the necessary air for the dilution; the LPG flow coming out the LPG bottles was rapidly diluted with the air. After, the LPG/air mix was injected in the middle of the performed hose (see figure 1). As an additional security measure, we also connected an automatic LEL detector to measure the LPG concentration in the hose. This detector was programmed to stop the LPG flow if the LEL concentration in the hose reached 50% of the LEL.

Sampling point

The resulting tracer concentrations were measured in the sampling point. We use an on-line C2-C6 Syntech Spectras gas cromatograph (GC) to measure the n-propane resulting concentrations at 30 minutes intervals. The advantage of using an on-line GC is that it records continuously the tracer concentrations, and thus, it is possible to collect a large amount of information under different

meteorological and traffic conditions. Therefore, the EFs estimated using this database represent well the real-word-emissions. In additions, since the GC also measured other C2-C6 VOCs, the measured concentrations of these VOCs can be used to estimate their EFs. In this project we measured 15 additional VOC species for which we estimated their EFs. Note that although the GC also measured n-butane and i-butane, we didn't use this information to estimate their EFs because the LPG has large concentrations of these substances.

In addition to VOCs concentrations, we registered weather information and we also performed traffic counts during the whole tracer experiment.

Estimation of the EFs

Figure 2 illustrates the variables involve in the emission and dispersion of pollutants at street level. Equation 1 shows the linear relation between EFs, the dispersion of the pollutants and their resulting concentrations[8]:

Figure 2. *Left:* **variables involve in the emission and dispersion of pollutants at street level.** *Right:* **Estimation of the emission factor (q)**
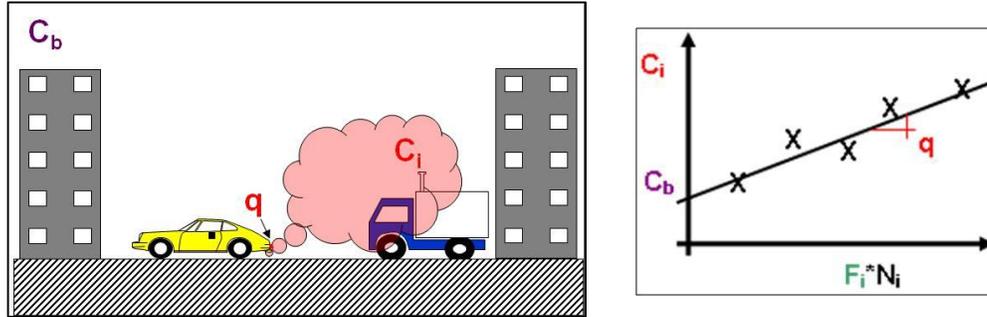
$$C_i = q * F_i * N_i + C_{b,i} \qquad (1)$$

Where,

C_i = Concentration of a particular pollutant in the street at any time i (μgm^{-3})
q = is the emission factor (EF) of the pollutant (mg veh^{-1} Km^{-1})
N_i = traffic flow rate along the street (veh s^{-1})
F^i = Dispersion factor of the pollutants (s m^{-2})
$C_{b,i}$= Background concentration of the pollutant (μgm^{-3})

F_i is a complex function of meteorology (wind speed, wind direction, mixing height, etc), the geometry of the street (buildings height, street width, etc), and the traffic induced turbulence. Here we propose to estimate the dispersion factor from the tracer study as follows:

$$F_i = C_{t,i}/E \qquad (2)$$

Where,

$C_{t,i}$ = Tracer concentration measured at the sampling point at any time i
   ($\mu g\ m^{-3}$)
E = Linear constant emission rate (1.05 x 10^{-3} g m^{-1} s^{-1})

Once the dispersion factors are known, the emission factor (q) of a pollutant can be calculated from the slope of the linear regression of the F_i*N_i vs. C_i plot. The intercept of that plot is the average background concentration. The dispersion factors (F_i) are independent of the pollutant type and then they can be used to estimate the emission factors for any pollutant monitored. In this case, this method is used to estimate the EFs of the 15 VOC species measured.

Effect of the emission source position

Due to logistical reasons, in the HCMC tracer experiment it wasn't possible to place the performed hose in the middle of the street; this would represent in a better way the traffic emissions. Moreover, road traffic emissions are produce in the full length and width of the street. Thus, the use of a finite emission line may produce an error on the estimated EFs. Therefore, we used the Computational Fluids Dynamics (CFD) model *WinMiskam* to evaluate the effect of the source position, its length and width, on the estimated dispersion factors and hence the EFs.

As a first stage, we used the results of the tracer study to validate the CFD model[9]. After, we used the CFD model to estimate the dispersion factors when the passive tracer is emitted from the full length and width of the street, in the same way road traffic emissions are produced. After, we computed the difference between these dispersion factors and the ones calculated from the HCMC tracer experiment[10]. In addition, other tracer source configurations were evaluated, these source configurations may be used in future studies to estimate more accurately the EFs. In this case, we used different emission line lengths, starting from a point source to a 200 m emission line. We also changed the position of these emission lines from one site of the street to the middle of the street.

RESULTS

Figure 3 shows some of the source configurations evaluated and the dispersion factors estimated from these sources.

Figure 3. *Left***: Source configurations evaluated.** *Right***: dispersion factors estimated from these sources**
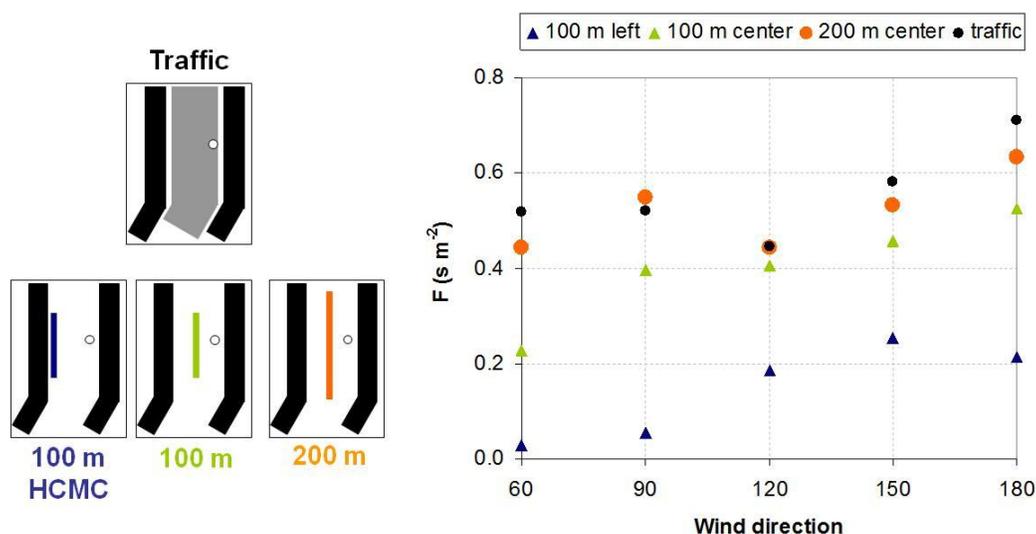
As can be seen, there are large difference between the dispersion factors estimated from the source configuration that represents the traffic emissions and the ones estimate from the HCMC tracer

experiment. Anyhow, these differences can be used to correct these dispersion factors and then. the corrected dispersion factors where used to compute the EFs. It is also possible to conclude that the source configurations that better represent the traffic emissions are the one located in the middle of the street and thus these source configurations should be used in future studies to avoid the previous correction.

Table 1 presents the VOCs EFs estimated for HCMC and the EFs estimated for these pollutants in other studies. This comparison indicates that the EFs estimated by means of the method proposed here are within the range of EFs estimated in other studies.

Table 1. VOCs EFs estimated for HCMC (mg veh^{-1} Km^{-1}), and comparison with available studies

	HCMC	Taipei[11]	Chung-Liao[12]	Taipei[13]
Propene	7.6	11.6	10.4	23
Trans-2-Butene	2.1	1.6	0.8	-
1-Butene	1.9	8.3	10.7	-
Cis-2-butene	2.0	1.8	1.6	-
i-Pentane	34	12.5	40.1	118
n-Pentane	9.8	9.5	19.3	16
Trans-2-Pentene	7.4	2.8	4.1	-
1-Pentene	2.3	1.6	1	-
2-methyl-2-butene	1.9	-	-	-
Cis-2-Pentene	2.2	1.6	1.6	-
2,3-Dimethylbutane	5.2	-	12.7	-
2-Methylpentane	5.6	-	12.6	22
3-Methylpentane	27.4	-	5.6	24
n-Hexane	56.2	4.2	5.7	-
Benzene	7.5	12.2	5.9	20

This study. LDV: 99.5% (motorcycles: 95%); HDV: 0.5%
[11] Taipei tunnel study. LDV: 93%; HDV: 7%
[12] Chung-Liao tunnel. LDV: 85%; HDV: 15%
[13] EFs for 4-strokes motorcycles, estimated from dynamometer test.

CONCLUSIONS

In this work we present a new method to estimate road traffic emission factors. EFs are estimated at real urban conditions and for a representative sample of vehicles. Moreover, since we know the amount of tracer released, the dispersion is more accurately estimated and then it reduces the uncertainties of the estimated EFs. Up to our knowledge this is the longest tracer study reported to date, this was only possible due to the tracer selected and the experimental set up used.

We used a Computational Fluid Dynamics Model (CFD) to evaluate the proposed methodology. This evaluation showed that there are large differences between the dispersion factors estimated from the source configuration that represents the traffic emissions and the ones estimate from the HCMC tracer experiment. In the case of HCMC, These differences were used to correct the dispersion factors. We also used this CFD model to evaluate other emission source configurations, the evaluation showed that the source configurations that better represent the traffic emissions are the one located in the middle of the street and thus these source configurations should be used in future studies to avoid the previous correction.

The methodology presented in this work serve for different proposes and their use can provide useful information for the air quality assessment. Results from the tracer study can be used to estimate the EFs under real urban conditions; it can be also used to validate near road dispersion models which in turn can be used in the future to evaluate abatement strategies.

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KEYWORDS

Mobile sources; Real-world motor vehicle emissions; Emission factors; Tracer studies

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