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EMISSION FACTORS FOR LIGHT-DUTY VEHICLES EQUIPPED WITH THREE-WAY CATALYTIC CONVERTER BASED ON MICRO-REACTOR STUDIES: A PROPOSAL FOR AMMONIA, NITROUS OXIDE AND MOLECULAR HYDROGEN

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Abstract

In this work, we report a methodology to provide emission factors based on micro-reactor studies. We propose emission factors for ammonia (NH_3 , 158 mg/km), nitrous oxide (N_2O , 322 mg/km) and molecular hydrogen (H_2 , 72 mg/km) for vehicles equipped with three-way catalytic converter (TWC). Our experimental conditions were similar to those prevailing on vehicles during catalyst light-off and transient urban driving cycle. NH_3 and H_2 emission factors reported in this work are quantitatively similar to those reported from vehicles. However, for N_2O our results are almost 6 times higher than the average reported from vehicles during catalyst light-off. It is possible that the emission factor of N_2O from light-duty vehicles reported during catalyst light-off is underestimated because the time (8.4 min) for recollecting the N_2O emission contained in the exhaust gases is largest than the time (4 min) required to produce the main emission of N_2O on the three way catalyst.

The methodology represents one of the first attempts to predict emission factors from a micro-reactor. Besides, our proposal has the advantage that the main parameters involved in the formation of NH₃, N₂O and H₂ can be controlled. Our method also complements the experimental strategies to estimate emissions, which are difficult to observe during the measurements of these compounds on vehicles.

Keywords: ammonia, emission factors, greenhouse gases, hydrogen, nitrous oxide

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1. Introduction

The emission factor is defined by the Environmental Protection Agency (US-EPA) from the United States (EPA, 2005) as a "representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant". Emission factors are relevant because they can be used to develop control strategies, control programs and appropriate mitigation strategies by environmental agencies. Emission factors also may be appropriate to estimate inventories. The emission inventory is the base-line for local (urban and rural inventories) and regional (national inventories) scale air quality management (EPA, 1995; IPCC, 2007).

In the case of urban inventories, the emission by cars and other vehicles are of primary importance. However, there are still inconsistences between estimated inventories and measurements, in particular

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of compounds such as nitrous oxide (N₂O), a compound linked to global warming, or ammonia (NH₃) another unregulated compound that has significant reactivity in the atmosphere (Fraser and Cass, 1998; Heeb et al., 2006a; IPCC, 2007; Salcedo et al., 2006). Besides, there is a new compound, molecular hydrogen (H₂), emitted from cars that is not included as part of the inventories, in spite that this no yet-regulated compound could be involved in the atmospheric cooling and ozone depletion (Tromp et al., 2003).

Up to now, emission factors for NH₃ and N₂O to estimate inventories have only been reported by cars from tunnel studies, dynamometer studies, remote sensing measurements, and measurements of emissions on real-time or modal models (Becker et al., 1999; Durbin et al., 2002; Fraser and Cass, 1998; Huai et al., 2003; Huai et al., 2004; Huai et al., 2005). H₂ emission factors were reported from dynamometer studies (Heeb et al., 2006b). However, the estimation of emission factors based on micro-reactor studies for light-duty vehicles equipped with TWC has not been reported. The methodology to estimate NH₃, N₂O and H₂ emission factors from cars is influenced by several factors including vehicle characteristics, traffic behavior, catalyst age, fuel quality and even meteorological conditions.

For instance, Huai et al. (2004) in a study to estimate the emission rate of N₂O from light-duty vehicles concluded that control technology, sulfur in gasoline and start conditions must be considered to estimate N₂O emission from vehicle inventories. Similar results were reported by Durbin et al. (2004), Huai et al. (2003) and Heeb et al. (2006b) for NH₃. They concluded that the air-to-fuel ratio and the sulfur level in gasoline, as well as vehicle technology and age are factors that contribute to NH₃ production by cars. In the case of H₂, Heeb et al. (2006a) reported that transient driving patterns have a major impact on the molecular H₂ emission.

We have previously reported on the importance of NH_3 , N_2O and H_2 emissions based on micro-reactor studies that closely match emission's reports from vehicles, yet have the advantage of close control of the operating conditions (Mejia-Centeno et al., 2007; Mejia-Centeno et al., 2009; Mejia-Centeno et al., 2012). However, there is no proposal to study vehicle emission factors based on data obtained from microreactor, where the operating conditions or reaction conditions are similar to those prevailing under real driving conditions.

In this work, we report a methodology to provide emission factors based on micro-reactor studies that give us further insight upon the emissions of NH₃, N₂O and H₂ during catalyst light-off and transient urban driving cycle using two different converters. Our methodology complements the experimental strategies to estimate the emissions, which are difficult to observe during the measurements of these compounds on cars.

2. Methods

2.1. Commercial converters

Two types of commercial TWC were employed in this work. They are roughly representative of those used in the nearly 3.5 million light-duty vehicles of the Metropolitan Area of Mexico City (Schifter et al., 2008). The first one, labeled Pd-only (Peasa L. Tech., model 200 EX series) has 400 cells per square inch (cpsi). The second one is a tri-metallic converter, labeled Pt-Pd-Rh-TWC, also with 400 cpsi. For Pd-only TWC, the Pd loading was $2.29x10^{-4}$ g/cm³. The tri-metallic converter contained Rh (8.12x10⁻⁵ g/cm³), Pd (7.06x10⁻⁶ g/cm³), and Pt (3.28x10⁻⁴ g/cm³).

2.2. Micro-reactor tests

The experiments were designed to represent emissions under cold start and transient urban driving over a simulated urban route. The air-to-fuel ratio, which is strongly correlated to transient vehicle operation, is the most important parameter (Heeb et al., 2006a). Based on the air-to-fuel ratio (Heeb et al., 2006a; Huai et al., 2003), it is possible to simulate the urban route followed by the US Federal Test Procedure, FTP-75, used for certification of new vehicles.

Fuel rich combustion in the car engine, prevailing when accelerating the vehicle, is similar to rich operating conditions of the micro-reactor. Short periods of lean combustion, frequent during deceleration, are equivalent to lean operation of the micro-reactor. Monolith samples of 16 channels (4x4 and 0.57 cm x 0.57 cm x 1.73 cm, 0.3270 g for Pdonly and 0.57 cm x 0.55 cm x 0.97 cm, 0.1796 g for Pt-Pd-Rh-TWC) were tested in a tubular quartz reactor mounted in a temperature-programmed electric furnace. A porous quartz frit disk was placed in the middle of the tube to support the monolith. The monolith was surrounded with quartz fiber to force the flow through the channels. Before the activity measurements, the monolith samples were heated to 600°C for 2 h under flow of 100 cm3/min of N2. Six flow controllers were used to measure the flow rates of NO+N2, C3H8+N2, CO+H2+N2, O2+N2, SO2+N2 and N2. Certified standard N2 and gas mixtures were purchased from Infra and Praxair (Mexico). H₂O was delivered by a syringe pump and it was vaporized in heated lines at 120°C before reaching the reactor. The setup used to estimate the emission rate of NH₃, N₂O and H₂ is detailed in Fig. 1.The analysis of reactants and products was made on-line by means of a NOx detector (Rosemount 951 A analyzer) and two gas chromatographs (HP 6890 equipped with a flame ionization detector (FID) and a thermal conductivity detector (TCD) employing a H Plot Q column, and a Shimadzu 12A equipped with a TCD employing a molecular sieve 5A column) to quantify C_3H_8 , H_2 , O_2 and CO.



Fig. 1. Micro-reactor setup used to determine emissions

Also a Fourier transform-infrared (FTIR) spectrophotometer (Bruker Tensor 27) equipped with a 0.75 m path-length gas-cell was employed on-line to quantify NH_3 and N_2O . Spectra were acquired at a 4 cm⁻¹ resolution by averaging 44 scans.

2.3. Light-off tests (Cold start)

The temperature at which catalytic reactions are initiated within the TWC is known as "*light-off temperature*", and the brief period when the engine and TWC are cold, after startup, is known as "*cold start*" (Kašpar et al., 2003). During the light-off experiments, a rich mixture was prepared adjusting the oxygen concentration to obtain an air-to-fuel ratio of 14.60 wt./wt. %. The composition of the mixture of gases was 2100 ppm of NO, 2200 ppm of H₂, 6600 ppm of CO, 515 ppm of C₃H₈, 10% (v/v) of H₂O and 0.53% (v/v) of O₂. The total feed rate was 950 cm³/min. The unit of ppm is in mole fraction. The temperature of the reactor was raised from room temperature up to 600°C with a heating rate of 2°C/min.

2.4. Transient urban driving test (at constant temperature, 500°C)

Our reaction conditions, temperature and airto-fuel ratio (A/F), as well as simulated exhaust gases, are qualitatively equivalent to those on the TWC when the vehicle is running under urban driving conditions. Rich operation on the micro-reactor is equivalent to brief acceleration periods. Lean operation is linked with deceleration periods on the engine of cars. Net rich conditions in this paper simulate large acceleration periods on the car engines. The exhaust gas was composed by the synthetic mixture reported in 2.3. Rich and lean mixtures were prepared by adjusting the oxygen concentration (Mejia-Centeno and Fuentes, 2009). The reactor was heated at 8° C/min from room temperature up to 500°C in a flow of 100 cm³/min of N₂ and stabilized for 1 h prior to the measurements.

2.5. Estimation of emission factors

Our approach to calculate emission factors for each compound is based on Eq. (1):

$$E_i = C_i \times MW_i \times F / 24.04 \tag{1}$$

where: E_i is the emission factor for the *i* compound (NH₃, N₂O or H₂) expressed in mg/km, C_i is the emission of the *i* compound in ppm by volume at 20°C, MW_i is the molecular weight for each compound and *F* is the total exhaust flow gas from vehicles, in m³/km. *F* is obtained using the fuel economy factor reported by US-EPA for light-duty vehicles (10.6 km/l), the gasoline density (740 kg/m³) and the air density (1.28 kg/m³ at 20°C and 1 atm) (Kean et al., 2009).

The total gas flow was obtained from the A/F ratio of the car engine. The magnitude for the F factor as a function of the A/F ratio is presented in Table 1. Appendix A presents a detailed procedure to obtain the F-factor.

3. Results and discussion

3.1. Light-off emission factors (Cold start)

When the vehicle first starts, the engine and converter are cold. The brief period when the engine and converter are cold is often known as "*cold start*". After start-up, the hot engine exhausts heat-up the converter to a temperature high enough to initiate the catalytic reactions. The temperature at which catalytic reactions are initiated within the catalytic converter is known as *"light-off temperature"*.

Air-to-fuel ratio, wt./wt. %	F-factor, m ³ /km
14.76 (L)	1.0348
14.70 (L)	1.0307
14.63 (S)	1.0260
14.60 (R)	1.0240
14.54 (R)	1.0199
14.44 (R)	1.0132
14.34 (R)	1.0064
14.21 (R)	0.9976

 Table 1. F-factor as a function of the air-to-fuel ratio¹

¹L, means lean, R, rich and S, stoichiometric conditions.

However, the light-off temperature is, in general, focused on the NO conversion. The temperature at which the NO conversion is 50%, expressed as T₅₀, is the reference for the light-off temperature for a particular converter. In this sense, a very fast light-off implies a high activity at low temperature on the converter. In our case, the light-off temperature (T₅₀) for NO was 250°C on the Pd-TWC. During light-off, NO reduction occurs via three pathways on the TWC. One involves the reaction of NO with CO and H₂ to produce N₂O, a second one produces NH₃ through the reduction of NO by hydrogen at high temperature, above 300°C, and the third one that represents the preferred reaction to form N₂ during NO reduction by CO and H₂, see Fig. 2. H₂ is formed on the TWC via the water gas-shift (WGS) and steam reforming (SR) reactions (Mejia-Centeno et al., 2012).



Fig. 2. Light-off emission rate for NH₃, N₂O and H₂ over Pd-only TWC under rich conditions from micro-reactor. The F-factor used was 1.0240 m³/km; corresponding to an air-to-fuel ratio of 14.60 wt./wt. %. The arrows show the corresponding axis for N₂O, NH₃, H₂, and temperature

The integrated mean emissions (mean, maximum, media and standard deviation) for NH_3 , N_2O and H_2 and the emission factors that we propose are presented in Table 2. The emission factors

proposed in Table 2 were obtained from Fig. 2. The temperature range considered to obtain the emission factors is also presented in Table 2. Huai et al. (2004) have reported emission factors for N_2O of 51 mg/km for Tier 1 vehicles, 44 mg/km for low emission vehicles (LEV) and 14 mg/km for ultra-low emission vehicles (ULEV) during cold-start ST01 driving cycle.

In the case of NH₃, Heeb et al. (2006b) reported light-off emission factors ranging between 21 and 74 mg/km. Huai et al. (2003) reported an emission factor of 20 mg/km of NH₃ during catalyst light-off. Durbin et al. (2004) reported a peak of 3.5 mg/s of ammonia over the FTP driving cycle on a ULEV light-duty truck and 8 mg/s of ammonia over the US06 cycle for the same ULEV vehicle. However, they did not report an integrated light-off emission factor for ammonia during their experiments. The emission factor for ammonia proposed in this work, 42 mg/km, is close to that reported by Heeb et al. (2006a). However, the emission factor for N₂O, 322 mg/km, is almost 6 times higher than that reported by Huai et al. (2004) for Tier 1 vehicles (51 mg/km).

 Table 2. Integrated emission factors during simulated light-off

Pd-only TWC	N ₂ O	NH3	H_2
Mean (mg/km)	322	42	114
Max	944	85	185
Media	202	40	125
Std. deviation	348	24	61
Temperature (°C) ¹	100-340	280-600	300-600

¹Temperature range considered to obtain emission factors

Winer and Behrentz (2005) have suggested that the use of FTIR spectroscopy in the measurement of N2O concentrations in diluted exhaust samples and online-real-time analysis of N2O from cars is limited. One problem is the interference from the CO absorption bands. Besides, the FTP cycle has three phases: cold start, hot stabilized conditions, and hot start conditions. N₂O emission from the first phase (cold start) is collected during the first 505 s (around 8.4 minutes) over a projected distance of 5.78 km at 41.2 km/h average speed. However, the main N₂O emission from cars is produced during the first 4 minutes, with a heating rate of the converter close to 100°C/min (Huai et al., 2004). The slow heating rate employed in this work allowed us to analyze and quantify in more detail the spectra obtained by FTIR spectroscopy during light-off. We were able to deconvolute readily the spectra to properly quantify the amount of N₂O. Our results suggest that the actual urban inventories of N2O could be underestimated because the contribution from the vehicular sector is not properly accounted for. However, if we consider the peak of N₂O reported by Huai et al. (2004), which is 4.1 mg/s during the first 240 s (4 minutes) at 41.2 km/h average speed, the N2O emission factor during light-off (in average) would be close to 350 mg/km for light-duty vehicles. The emission factor for N2O from vehicles obtained during cold start during the first 4 minutes (350 mg/km) is very similar to that reported

in this manuscript (322 mg/km). It is then possible that the emission factor for N₂O from light-duty vehicles during cold start is underestimated because the time (8.4 min) for recollecting the N₂O emission contained in the exhaust gases is largest than the time required to produce the main emission of N₂O on the three way catalyst. We propose, then, that N₂O emission from the first phase (cold start) of the FTP cycle must be collected during the first 4 min, instead of the 8 min, as is actually considered.

In the case of H_2 , Heeb et al. (2006a) reported emission factors from 11 to 273 mg/km for different driving cycles. Durbin et al. (2004) reported that 220 mg of H_2 are produced during the first part of the coldstart, whereas about 200 mg of H_2 are emitted after TWC light-off. We did not find emission factors for H_2 reported during catalyst light-off from cars, and therefore, we propose a light-off emission factor of 114 mg of H_2 /km for light-duty vehicles equipped with TWC.

3.2. Emission factors for transient urban driving at $500^{\circ}C$

Stop-and-go urban driving conditions with frequent periods of acceleration and deceleration were simulated between 14.5 and 14.8 wt./wt. % of the airto-fuel ratio in our setup, in agreement with Huai et al. (2003). To estimate the emission factors from vehicles under transient urban driving, we selected 500°C as the "equilibrium temperature" for the TWC. 500°C is the average temperature of the TWC over the FTP driving cycle (Huai et al., 2005). Besides, the temperature chosen correspond roughly to the value (500°C) reached when the velocity of the vehicle is close to 120 km/h, and represents the average temperature during highway driving conditions (Heeb et al., 2006a). We found that NH₃ and H₂ are formed under rich conditions. Under lean conditions, the selectivity of the converter changes to form N₂O, see Figs. 3 and 4. Our results suggest that NH₃ and H₂ are emitted from vehicles during acceleration events. N2O is produced during the deceleration periods of the car engine on the TWC. The integrated emission factors are reported in Table 3. It is important to note that emissions of NH₃ (212 mg/km) and H₂ (214 mg/km) produced on the tri-metallic converters are higher with respect to those produced on the Pd-only TWC (158 mg of NH₃/km and 72 mg of H₂/km). However, the emission of N₂O produced over both converters is very similar, close to 120 mg/km.

Our results of N_2O can be compared with emission factors determined from real-time studies and tunnel studies. For Instance, Huai et al. (2004) reported emission rates from 1.2 to 105 mg/km during the FTP driving cycle. Behrentz et al. (2004) suggested an average emission factor of 20 mg/km. Interestingly, Ball et al. (2013) reported around 5 mg/km of N_2O for low emissions vehicles at 550°C. In our case, we estimated an emission factor of 125 mg/km for vehicles running under urban driving pattern. For vehicles running at high speed, we estimated an emission factor of 47 mg/km. Our trend shows a larger emission ratio of N_2O (125 mg/km) for the city roads than for the highway (47 mg/km).

We also estimated an emission factor of 38 mg of NH₃/km for vehicles running under stop-and-go driving conditions and 260 mg of NH₃/km for vehicles traveling at high speed. The statement is based in the fact that during the stop-and-go driving pattern the airto-fuel ratio ranges between 14.54 and 14.80 wt./wt.%. When the vehicle travels at high speed, above 90 km/h, the air-to-fuel ratio ranges between 14.54 and 14.20 wt./wt. % (Heeb et al., 2006b; Huai et al., 2003). In this line, we found that on-road vehicles running under highway driving pattern are the main source of NH₃ in urban settings. Stop-and-go running vehicles have much lower impact because they operate close to stoichiometric conditions and NH₃ is not an issue then. In this sense, the average emission factor for NH₃ reported by Sun et al. (2014) from a mobile platform equipped with an open-path NH3 sensor was of 490 mg/kg of fuel, which is equivalent to 27 mg/km considering the economy factor proposed by the US-EPA of 13.6 km/l (32 MPG). The mean speed reported by Sun et al. (2014) was 43 and 32 km/h. Heeb et al. (2006) reported emission factors from 8 to 170 mg/km for ammonia when driving 70-90 km/h.



Fig. 3. Emission rates for vehicles running under transient urban driving cycle for NH₃, N₂O and H₂ at 500°C over a Pd-only TWC as a function of the air-to-fuel ratio (A/F). The simulated stop-and-go span the range 14.54 to 14.80 of the A/F ratio. For the simulated high speed, the A/F ratio ranges from 14.54 to 14.20 wt./wt. %

In the case of H_2 , we found that this compound is only emitted when the vehicle is running under rich conditions or during acceleration events. H_2 is not observed during deceleration of the car engine. We also found that emission of H_2 on the tri-metallic converter is larger respect to that Pd-only catalyst. In this line, it has been reported that (Whittington et al., 1995) Rh supported on Ce₂O₃/Al₂O₃ produces a large amount of H_2 via WGS and SR reactions compared with those catalysts containing Pt and Pd.



Fig. 4. Emission rates for vehicles running under transient urban driving cycle for NH₃, N₂O and H₂ at 500°C over a tri-metallic converter Pt-Pd-Rh-TWC as a function of the air-to-fuel ratio (A/F). The simulated stop-and-go span the range 14.54 to 14.80 of the A/F ratio. For the simulated high speed, the A/F ratio ranges from 14.54 to 14.20 wt./wt. %

The integrated emission factor that we propose for H_2 is 72 mg/km for vehicles equipped with TWC running under transient urban driving. The emission factor of H₂ reported in this work can be compared with emission factors reported from dynamometer studies from cars. In this line, Bond et al. (2010) reported emission factors between 6 and 69 mg/km for gasoline cars employing different urban, rural and highway driving cycles. The emission rate reported by Vollmer et al. (2007) for on-road vehicles running above 100 km/h of 67 mg/km agree very well with the emission factor that we are proposing of H₂ for Pdonly TWC. Moreover, the emission factor of H₂ reported by Heeb et al. (2006a) for vehicles running under German highway driving cycle, 153 mg/km, and stop-and-go R4, III (273 mg/km) urban driving pattern correlates with the emission factor reported in this work for the tri-metallic converter, which is of 214 mg/km. Our results consistently show that the emission factor for H₂ and in general for NH₃ and N₂O, reported in this work using a micro-reactor are qualitatively and quantitatively similar to those reported from vehicles running under real driving conditions.

It has been reported (Mejia-Centeno et al., 2007; Mejia-Centeno et al., 2009) that N_2O is produced on the TWC during NO reduction with CO and H_2 during catalyst light-off via reactions 2-3 at low temperature (between 110 and 320°C). NH₃ is formed in the 200-600°C range via reaction (4) by reduction of NO with H₂. The hydrogen required to produce ammonia is formed via steam reforming and water gas-shift reactions over the TWC (reactions 5 and 6). The formation of N₂O and NH₃ by NO reduction with CO and H₂ on the TWC has been widely reported (Mejia-Centeno et al., 2007; Mejia-Centeno et al., 2009; Shelef and McCabe, 2000;

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Kašpar et al., 2003). However, we propose that the formation of N_2O on the TWC, reported in Figs. 3 and 4, occurs by NO reduction with propane via reaction (7) under lean conditions at high temperature (500°C).

$$2NO + CO \to N_2O + CO_2 \tag{2}$$

$$2NO + H_2 \to N_2O + H_2O \tag{3}$$

$$2NO + 5H_2 \rightarrow 2NH_3 + 2H_2O \tag{4}$$

$$C_3H_8 + 3H_2O \rightarrow 7H_2 + 3CO \tag{5}$$

$$CO + H_2 O \to H_2 + CO_2 \tag{6}$$

$$12NO + C_3H_8 \to 2N_2O + 4H_2O + 3CO_2 + 4N_2 \quad (7)$$

The formation of N₂O reported in Figs. 3 and 4 at 500°C is supported by the emission of N₂O from light-duty vehicles reported by Ball et al. (2013) and Rahman et al. (2011). Ball et al. (2013) reported up to 5 mg/km of N₂O at 600°C from a vehicle equipped with a close-coupled TWC catalyst during the FTP running cycle. Rahman et al. (2011) reported close to 15 mg/km of N₂O from vehicles during the hot transient phase (the third phase) of the FTP75 driving cycle. It is important to note that the FTP cycle has three phases: (i) cold start, (ii) hot stabilized conditions and (iii) hot start conditions. The temperature on the converter during the hot transient phase (third phase) is around 550°C (\pm 50°C). We can conclude that there is an important emission of N₂O from light-duty vehicles running under hot stabilized conditions. In fact, we found that N₂O is produced during deceleration events.

 N_2O is formed on the TWC via NO reduction with propane under lean conditions at high temperature (around 500°C). However, the involved mechanism to produce N_2O by NO reduction with propane is not clear yet. More investigation is still needed in order to elucidate the reactions involved in this important emission of N_2O from light-duty vehicles equipped with TWC, which is linked to the global warming. It is then probably that the concentration of N_2O , and in general those of NH_3 and H_2 , continues increasing in the urban atmosphere in the near future.

4. Conclusions

We can conclude that our methodology based on micro-reactor studies to predict emission factors for light-duty vehicles equipped with TWC is successful for ammonia and molecular hydrogen. However, more investigation is still needed to understand the factors that affect the emission of N₂O during catalyst lightoff, particularly, the first 4 minutes after engine startup. The methodology provides new elements that complement the experimental strategies to estimate the emission factors, which are difficult to observe during the measurements of NH₃, N₂O and H₂ on vehicles.

	Pd-only TWC			Pt-Pd-Rh-TWC		
	N ₂ O	NH3	H ₂	N ₂ O	NH ₃	H ₂
Mean (mg/km)	125	158	72	113	212	214
Max	377	424	215	339	439	608
Media	0	89	34	0	227	130
Std. deviation	217	171	86	196	166	218
A/F ratio (wt./wt. %) ¹	14.63-14.76	14.63-14.21	14.63-14.21	14.63-14.76	14.63-14.21	14.63-14.21

Table 3. Integrated emission factors for vehicles running under transient urban driving cycle

¹A/F ratio considered to obtain the integrated emission factors

Besides, our proposal has the advantage that the main parameters to simulate real driving patterns of vehicles can be controlled. It is important to mention that the methodology used in this work represents the first attempt to predict emission factors at low cost with relatively simple infrastructure compared with methodologies involving cars. The results could be useful to improve the quality of emission inventories and the global performance of the next generation of TWC.

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