Air pollution emissions originated from intense vehicle trafic in urban tunnels CODE 0947

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Abstract. *The traffic of vehicles is one of the main sources for atmospheric pollutants in many urban areas. The estimate of these emissions is important for evaluating the quality of the air and possible adverse effects of pollution in the human health. The aim of this work is to apply the COPERT II model (Ahlvik et al., 1997) to the traffic in two urban tunnels in Rio de Janeiro, Brazil, for providing total emission estimates for NO_x, CO and VOC. Studies in tunnels are especially useful in this type of evaluation because the mobile sources can be investigated with little interference from other sources. Although the results show that occurred a reduction in the value of the emission factors for NO_x, CO and VOC for vehicles between 1991-2002, this effect was outbalanced by the large number of vehicles and occurred a higher emission of the investigated pollutants in two tunnels.*

Keywords: *Emission factors, emission model, mobile sources.*

1. Introduction

Air pollution in urban areas depends on different sources, but the most significant is road traffic and a worsening of the situation may be expected in view of the continuous increase of the number of vehicles. Anthropogenic emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOC) are the precursors of photochemical reactions which may contribute to the ozone formation in ambient air. Nitrogen oxides from mobile sources are also a major contributor to acidic deposition. Road tunnels in urban areas are affected by high levels of vehicle exhaust emission. In tunnels, elevated concentrations can be expected due to the fact that there are great emissions of air pollutants in a relatively small volume and possibly a poor ventilation. A major concern is the elevated human exposure to air pollutants, while driving through a road tunnel, which can represent a serious health hazard (Barrefors, 1996).

Traffic emissions may be calculated by multiplying an emission factor (EF) by parameters representing an activity level associated with each vehicle category (Corvalán and Urrutia, 2000). The emission factors are defined as the emitted mass of air pollutant per driven distance of a vehicle and may represent the actual traffic and driving conditions. Emission factor models have been widely used to estimate emission of the pollutants from mobile sources (Sallès, et al., 1995; Ntziachristos and Samaras, 2000). However, different models may provide different results, because a mobile source emission model can be affected by many factors as a result of variations in local driving behavior (e.g. new speed limit regulations in a particular area, etc.) and vehicle fleet. No single emission model is capable of meeting all these requirements simultaneously (Sturm, et al., 1997).

A comparative study of the emission factors for CO, VOC and NO_x was realized by Winther (1998) which employed the hot EF from COPERT II (COmputer Programme to Calculate Emissions from Road Transport), the German Workbook, the DTU model and the Danish measurements. The study also examined if the efficiency of the catalysts decreased at high speeds by using the DTU model. For cars with catalyst at high speed, the CO, VOC and NO_x emission factors obtained by COPERT II indicated a decrease of the catalyst efficiency, but this tendency was not verified in the Danish measurements. The high of CO emissions computed with the DTU model was 50-70% higher, compared with the other models, was due the high ECE 15/04 emission factors. The Danish data for VOC and NO_x total emissions were about 40 to 50% lower, respectively, than the emissions obtained from the other models. Mesink et al., (2000) implemented a traffic flow model to provide hourly emissions of CO, NO_x, VOC, PM, SO_2 and Pb for individual streets and road segments in the Antwerp. The EF used in the model are derived from COPERT II model. The results showed that comparisons of computed emission factors with measured in the chassis dynamometer test were different in magnitude and trend, e.g., an overestimation of the NO_x emission factors and an underestimation of the CO and VOC emission factors. In recent study Corvalán and Vargas (2003) investigated emission deterioration factors to the conditions of the vehicle fleet in Santiago de Chile. The EF obtained from based on experimental data collected from chassis dynamometer tests and applied MOBILE AP-42 and COPERT models. The deterioration factors found from experiments exceed in all cases the deterioration factors obtained two models. In the case of CO emissions, the resulted to be approximately 1.2 times the values obtained by AP-42 and COPERT. The NO_x emission deterioration factors from exceed 2.8 time the values predicted by the AP-42 model and 2.0 time the results obtained from COPERT model.

Various studies have investigated motor vehicle EF of NO_x, CO and VOC in road tunnels (John, et al., 1999, Hwa et al., 2002). In this work, the COPERT II model was selected to study the total emission estimates of NO_x, CO, VOC in road tunnels Zuzu Angel and Rebouças in the city of Rio de Janeiro, Brazil. The EF in emission model from based on a sample of the vehicle distribution in road tunnel and composition of the Brazilian gasoline (Petrobras, 2003). The sample gasoline vehicles were classified according with three engine capacities: < 1.4 l, between 1.4 – 2.0 l and > 2.0 l. This classification was used to provide EF factors were compatible with the CORINAIR/COPERT methodology (Ahlvik et al., 1997). The omission of the other vehicles category is made because gasoline cars has the most significant emissions of NO_x, CO and VOC and constitute a large proportion of the vehicle composition in these places.

2. The COPERT II emission model

The COPERT II model was developed by the European Environment Agency (Ahlvik et al., 1997) for usage in many countries with different characteristics (Ntziachristos and Samaras, 2000, Corvalán and Urrutia, 2000, Saija and Romano, 2002, Marmur and Mamane, 2003). The model estimates EF a wide range of pollutants, including: NO_x, CO, VOC and heavy metals (lead, cadmium, copper, nickel etc.). The COPERT II model considers both hot and cold-start operating conditions. The calculation is based on five main types of input parameters: (1) total fuel consumption: per fuel type and per vehicle category; (2) vehicle fleet: number of vehicles per vehicle category and age distribution of the vehicle fleet per vehicle category; (3) driving conditions: annual mileage per vehicle class, annual mileage per road type and average speed of vehicle; (4) emission factors: per vehicle class, per production year and per road type and (5) other parameters: fuel properties, climate conditions, road gradient (sttepness) and load of the vehicle (Ahlvik et al., 1997).

2.1.1 - Hot emission

The EF for hot running vehicles, as defined in the COPERT II model are a function of vehicle speed, vehicle category (passenger cars, light duty vehicles, heavy duty vehicles, urban buses and coaches), fuel type and cylinder capacity. The basic equation for estimating hot emissions from a vehicle by using emission factors is:

$$\textit{Emissions}\ [\mathrm{g}] = \textit{emission factors}\ [\mathrm{g/km}] \times \textit{kilometers traveled by vehicle per year}\ [\mathrm{km}] \quad (1)$$

The hot EF factors were calculated for each pollutant *i*, vehicle category *j*, road class *k* and fuel type *l*, by using the general formula:

$$E_{hot,i,j,k} = g_{j,k,l} b_{j,l} e_{*hot,year,i,j,k} \quad (2)$$

where $E_{hot,i,j,k}$ represents the emission of the pollutant *i* in [g], produced in the reference year by vehicles of category *j* on roads type *k* (urban, rural, and highway), with hot engine. The $g_{i,j,k}$ is the share for type 1 annual fuel consumption 1 used by vehicles of category j, driven on road type *k*, $b_{i,j}$ is the total annual consumption for fuel type l [kg] by vehicles of category *j* operated in the reference year, $e_{*hot,year,i,j,k}$ is the average fleet representative baseline emission factor in [g/kg fuel] of the pollutant *i*, relevant for the vehicle category *j*, operated on roads of type *k*, with hot engines.

3. Methodology

The COPERT II model was applied for calculating the amount of emission of NO_x, VOC and CO for the vehicle distribution in the Zuzu Angel and Rebouças tunnels of the city Rio de Janeiro. Both tunnels have two galleries. It was employed the model data for Greece in an attempt to obtain the best available estimates for the emission factors of the Brazilian vehicles. The Zuzu Angel tunnel has 1.59 km in length and two lanes per gallery (one gallery for each direction), while the Rebouças tunnel has 2.8 Km in length and three lanes per gallery (one gallery for each direction). The Tab. (1) shows the composition of the total vehicle fleet of city Rio de Janeiro. In the Zuzu Angels tunnel the traffic counts were obtained from loop detectors while the Rebouças tunnel the counts and vehicle category were obtained from loop detectors and high resolution video observations. The Tab. (2) shows the distribution of the vehicle fleet in the Zuzu Angel tunnel and the Tab. (3) shows the distribution of the vehicle fleet in the Rebouças tunnel.

Table 1. Composition of the total vehicle fleet in the city Rio de Janeiro.

	2002 / NOVEMBER		2003 / JANUARY	
VEHICLE TYPE	**TOTAL**	**PERCENTAGE (%)**	**TOTAL**	**PERCENTAGE (%)**
Passenger car	1494118	84.63	1501969	84.54
Light Duty Vehicle	128896	7.30	129948	7.31
Heavy Duty Vehicle	30727	1.74	30942	1.74
Buses	11050	0.62	11022	0.62
Mopeds	7742	0.44	8204	0.46
Motorcycle	92821	5.26	94532	5.32
TOTAL FLEET	1765354	100.00	1776617	100.00

Source: Transit Department for the State of Rio de Janeiro, Brazil. (Detran – RJ, 2003).

Table 2. Distribution of the vehicle fleet in the Zuzu Angel tunnel based on loop detectors, in the year of 2002.

DIRECTION	BARRA / LAGOA	LAGOA / BARRA
DAY / MONTH	**NUMBER OF CARS**	**NUMBER OF CARS**
10 June	46647	53911
17 June	45477	47902
TOTAL FLEET	95124	101813

Source: Coordenadoria de Vias Especiais – CVE / Centro de Controle Operacional (CCO) – Zuzu Angel Tunnel . City Hall of Rio Janeiro – Brazil.

Table 3. Distribution of the vehicle fleet in the Rebouças tunnel based on loop detectors and on the vehicle category obtained from high resolution video observations, in the year of 2002.

	LAGOA / SÃO CRISTÓVÃO				SÃO CRISTÓVÃO / LAGOA			
DAY MONTH	**MOTOR CYCLE**	**PASSENGER CARS**	**LIGHT DUTY VEHICLE**	**HEAVY DUTY VEHICLE**	**MOTOR CYCLE**	**PASSENGE R CARS**	**LIGHT DUTY VEHICLE**	**HEAVY DUTY VEHICLE**
23 01	2384	87918	410	1543	3573	81569	492	1598
22 02	3066	92083	443	1687	18923	74256	421	1510
22 03	2780	96141	543	1629	2874	92168	704	1627
23 04	1487	77248	472	1004	1293	72874	546	988
22 05	2378	81995	417	1600	2069	83610	463	1608
30 06	830	59516	352	802	723	56171	414	762
23 07	2792	97165	476	1660	2582	94103	539	1645
23 08	2976	98509	484	1652	2628	93927	553	1659
04 09	1297	76456	381	924	1297	74612	504	948
23 10	2470	88489	425	1536	2696	90316	483	1602
23 11	2976	98509	484	1652	2628	93927	553	1659
23 12	2625	92334	451	1594	2137	90066	553	1558
TOTAL	28061	1046363	5338	17282	43423	997599	6225	17164

Source: Coordenadoria de Vias Especiais – CVE / Centro de Controle Operacional (CCO) – Rebouças Tunnel . City Hall of Rio Janeiro – Brazil.

The Tab. (4) presents Brazilian gasoline specifications used in the COPERT II model for calculating emission factors for NO_x, CO and VOC. Nowadays, all Brazilian gasoline has a legal alcohol content requirement between 20% to 24%, with a variation of + or – 1%. The actual content is defined by the Inter-ministerial Council for Sugar and Alcohol (CIMA - Conselho Interministerial de Açúcar e Álcool, 2003). Assuming that the gasoline is composed by 24% of ethanol and 76% of gasoline, and that the density of the ethanol is 0.7915 kg/l and that the density of the gasoline is 0.7350 kg/l (PETROBRAS, 2003), results that: 1 liter of fuel = 0.24 x 0.7915 kg of ethanol + 0.76 x 0.7350 kg of gasoline = 0.18996 kg of ethanol + 0.5586 kg of gasoline = 0.7485 kg of fuel.

Table 4. Brazilian gasoline specifications.

CHARACTERISTIC	COMMOM GASOLINE – TYPE C
Reid Vapor Pressure (37.8 ^{o}C)	49.0 min and 69.0 max. (1)
Lead content (g/l)	0.005
Sulphur content (%)	0.10 max.
Copper (mg/kg)	0.07
Chormium (mg/kg)	0.00
Nickel (mg/kg)	default
Zinc (mg/kg)	default
Selenium	default
H:C ratio	5.5 to 6.0
Ethanol (%)	20 to 24

(1) For April, May, June, July, August, September, November: add 7 to max. value.
Source: Petrobras and ANP.

4. Results and discussion

The EF for gasoline passenger cars used in this work for calculating hot emissions of NO_x, CO and VOC were obtained by using Eq. (2). The gasoline passenger cars were classified into three cylinder capacities (< 1.4 liter, between 1.4 – 2.0 liter and > 2.0 liter) and sub-divided in eight subclasses according to model year, following the CORINAIR/COPERT methodology (Ahlvik et al., 1997). The estimate for the gasoline vehicle category, the production year, the engine capacity, and the reduction technology (catalytic, fuel injection and canister) were obtained by traffic counts and license plate identification from annotations of the vehicle fleet in both the Zuzu Angel and the Rebouças tunnels, for two hours observations, the data appears on Tab. (5) and Tab. (6), respectively. These observations were conducted in November 2002 (Zuzu Angel tunnel) and January 2003 (Rebouças tunnel). The resulting distribution for gasoline vehicles in the Zuzu Angel tunnel totalized 90.22%, while in the Rebouças tunnel it was 78.00%.

Table 5. Distribution of the vehicle fleet in the Zuzu Angel tunnel during the study based in license plate identification, from 17 p.m. to 19 p.m. on 8 November 2002.

	PASSENGER CAR - GASOLINE					
	CYLINDER CAPACITY < 1.4 l		**CYLINDER CAPACITY 1.4 – 2.0 l**		**CYLINDER CAPACITY > 2.0 l**	
	NUMBER OF CARS	**(%)**	**NUMBER OF CARS**	**(%)**	**NUMBER OF CARS**	**(%)**
	821	**36.67**	**1014**	**45.29**	**48**	**2.14**
PRE ECE	2	0.09	0	0.00	0	0.00
ECE 15/00	5	0.23	1	0.04	0	0.00
ECE 15/02	2	0.09	3	0.13	0	0.00
ECE 15/03	2	0.09	2	0.09	0	0.00
ECE 15/04	9	0.40	28	1.25	0	0.00
91/441/EEC	142	6.34	251	11.21	2	0.09
94/12/ECE	226	10.09	321	14.34	22	0.98
EC Proposal I	433	19.34	408	18.23	24	1.07
			NUMBER OF CARS		**(%)**	
PASSENGER CAR - DIESEL			37		1.65	
PASSENGER CAR- LPG			119		5.31	
PASSENGER CAR - ALCOHOL			63		2.81	
			LIGHT DUTY GASOLINE VEHICLES			
< 3.5 t			137		6.12	
TOTAL OBSERVED FLEET:			**2239**		100.00	

Source: Observations of the license plate by PUC-Rio students, 2002/08/11.

Table 6. Distribution of the vehicle fleet in the Rebouças tunnel during the study based in license plate identification, from 17:20 p.m. to 19:20 p.m. on January 2003.

	PASSENGER CAR - GASOLINE					
	CYLINDER CAPACITY < 1.4 l		**CYLINDER CAPACITY 1.4 – 2.0 l**		**CYLINDER CAPACITY > 2.0 l**	
	NUMBER OF CARS	**(%)**	**NUMBER OF CARS**	**(%)**	**NUMBER OF CARS**	**(%)**
	801	**48.14**	**423**	**25.42**	**42**	**2.52**
PRE ECE	1	0.06	0	0.00	0	0.00
ECE 15/00	10	0.60	3	0.18	0	0.00
ECE 15/02	6	0.36	2	0.12	0	0.00
ECE 15/03	6	0.36	9	0.54	0	0.00
ECE 15/04	5	0.30	21	1.26	0	0.00
91/441/EEC	141	8.48	148	8.89	11	0.66
94/12/ECE	277	16.65	121	7.27	16	0.96
EC Proposal I	355	21.33	119	7.15	15	0.90
			NUMBER OF CARS		**(%)**	
PASSENGER CAR - DIESEL			39		2.34	
PASSENGER CAR- LPG			259		15.57	
PASSENGER CAR - ALCOHOL			64		2.81	
			LIGHT DUTY GASOLINE VEHICLES			
< 3.5 t			36		2.16	
TOTAL OBSERVED FLEET:			**1664**		100.00	

Source: Observations of the license plate by PUC-Rio students, 2003/01/25.

In this study the emission factors were obtained by using COPERT II model as a function of the speed, road urban, Brazilian gasoline composition, reid vapor pressure of the Brazilian gasoline (Petrobras and ANP, 2003) and ambient temperature of the year 2002 (Instituto Nacional de Meteorologia, 2003).

The Tab. (7) shows the NO_x emission factors as a function of speed for cylinder capacity < 1.4 l. For NO_x, the EF increase with the increase of speed, but the effect of construction year was greater than the effect of speed. This effect was more significant for vehicles categories 91/441/EEC (1991-1996), 94/12/ECE (1997-1999) and EC Proposal I (pos-2000), where occurred an average reduction in the EF of about 76.16%, 90.85% and 91.95%, respectively, in relation to ECE 15/04 (1985-1990). For 94/12/ECE and EC Proposal I emission factors were below the limit established by Brazilian legislation control of vehicle emissions: 0.6 g/km cars after 1997 (Program for Controlling Air Pollution by Automotive Vehicles, PROCONVE - established by CONAMA through the Administrative Rule N° 18 /1985). This indicates that the main influence is due to the presence of the fuel injection and catalytic converter, in there two categories where 100% of the vehicles have these equipments.

Table 7. Emission factors for NO_x and cylinder capacity <1.4 l obtained by using COPERT II model for Rio de Janeiro conditions.

EMISSION FACTOR NO_x (g/km) - CYLINDER CAPACITY < 1.4 l									
SPEED (km/h)	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
PRE ECE	1.567	1.722	1.849	1.948	2.019	2.062	2.077	2.064	2.023
ECE 15/00 01	1.567	1.722	1.849	1.948	2.019	2.062	2.335	2.064	2.023
ECE 15/02	1.477	1.530	1.619	1.744	1.905	2.012	2.335	2.604	2.909
ECE 15/03	1.548	1.589	1.680	1.821	2.012	2.253	2.544	2.885	3.276
ECE 15/04	1.523	1.597	1.691	1.804	1.937	2.089	2.261	2.452	2.662
91/441/EEC	0.401	0.375	0.361	0.358	0.366	0.386	0.418	0.515	0.581
94/12/ECE	0.177	0.165	0.159	0.158	0.161	0.170	0.184	0.203	0.277
EC Proposal I	0.160	0.150	0.144	0.143	0.146	0.154	0.167	0.184	0.206

The Tab. (8) shows the CO emission factors as a function of speed for cylinder capacity < 1.4 l. In this case, for CO, the emission factors decrease with the increase of speed. Again the effect of construction year was greater than the effect of speed and this effect was more significant for vehicles categories 91/441/EEC, 94/12/ECE and EC Proposal I. For 94/12/ECE emission factors were below the limit established by Brazilian legislation control of vehicle emissions, 2.0 g/km cars after 1997 (PROCONVE). But for 20 km/h the EF exceeded this limit. The result shows that the emission factors were greater low for EC Proposal I and below of the limit established by PROCONVE.

Table 8. Emission factors for CO and cylinder capacity < 1.4 l obtained by using COPERT II model for Rio de Janeiro conditions.

EMISSION FACTOR CO (g/km) - CYLINDER CAPACITY < 1.4 l									
SPEED (km/h)	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
PRE ECE	42.565	32.970	27.505	23.898	21.304	19.333	17.773	16.502	15.520
ECE 15/00 01	32.119	23.601	18.966	14.920	14.380	14.480	15.220	16.600	18.620
ECE 15/02	27.555	19.946	15.859	13.275	9.220	8.200	7.700	7.720	8.260
ECE 15/03	24.695	20.913	16.752	13.345	10.692	8.793	7.648	7.257	7.620
ECE 15/04	17.075	11.806	9.807	7.417	6.283	4.956	4.502	4.280	4.292
91/441/EEC	3.254	2.592	2.121	1.841	1.753	1.856	2.151	2.637	3.314
94/12/ECE	2.777	1.813	1.483	1.287	1.225	1.297	1.503	1.843	2.317
EC Proposal I	0.488	0.389	0.318	0.276	0.263	0.279	0.323	0.396	0.498

Emission factors for VOC are presents in Tab. (9) as a function of speed for cylinder capacity < 1.4 l. The emission factors decrease with the increase of speed and the effect of construction year also was greater than the effect of speed for vehicles categories 91/441/EEC (1991-1996), 94/12/ECE (1997-1999) and EC Proposal I (pos-2000). The EF obtained for VOC were low, this behavior was probably due the analysis of hot emissions in this work and evaporative control (canister since 1988 in Brazil, PROCONVE-CONAMA, 1986).

Table 9. Emission factors for VOC and cylinder capacity <1.4 l obtained by using COPERT II model for Rio de Janeiro conditions.

EMISSION FACTOR VOC (g/km) - CYLINDER CAPACITY < 1.4 l									
SPEED (km/h)	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
PRE ECE	3.805	2.875	2.354	2.017	1.777	1.597	1.456	1.342	1.247
ECE 15/00 01	3.033	2.280	1.862	1.398	1.319	1.256	1.204	1.160	1.121
ECE 15/02	3.033	2.270	1.849	1.577	1.134	1.061	1.006	0.969	0.950
ECE 15/03	3.033	2.270	1.849	1.577	1.134	1.061	1.006	0.969	0.950
ECE 15/04	2.393	1.807	1.480	1.268	1.118	0.895	0.794	0.728	0.698
91/441/EEC	0.305	0.219	0.151	0.100	0.067	0.051	0.053	0.071	0.108
94/12/ECE	0.134	0.096	0.066	0.044	0.029	0.022	0.023	0.031	0.047
EC Proposal I	0.122	0.088	0.060	0.040	0.027	0.020	0.021	0.029	0.043

The Fig. (1), Fig. (2) and Fig. (3) show the EF for NO_x, CO and VOC as a function of speed for 91/441/EEC (1991-1996), 94/12/ECE (1997-1999) and EC Proposal I (pos-2000) cars > 2.0 l, respectively. The EF for NO_x, CO and VOC decrease with the increase of speed even about 60 km/h, but at high speeds these emission factors increase. For NO_x in all vehicles categories the EF were below of the limit established by Brazilian legislation control of vehicle emissions: 0.6 g/km cars after 1997 and also EF for CO: 2.0 g/km cars after 1997. This behavior was resulting of modern gasoline cars with catalytic converters (since 1997 in Brazil PROCONVE-CONAMA, 1986) and fuel injection (about since 1992 for car > 1.0 l).

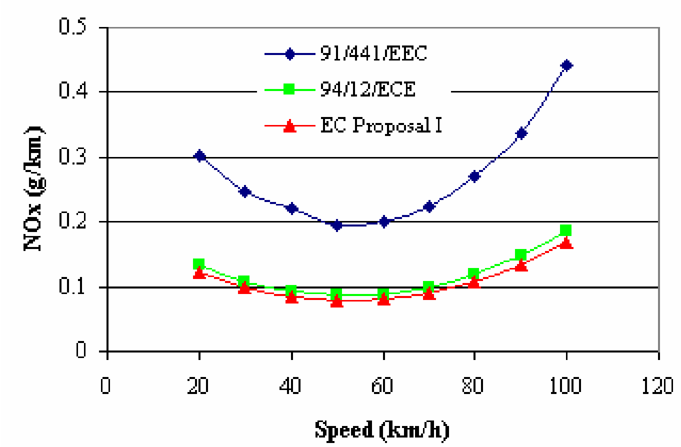

Figure 1. Emission factors for NO_x and cylinder capacity > 2.0 l, obtained by using COPERT II model.

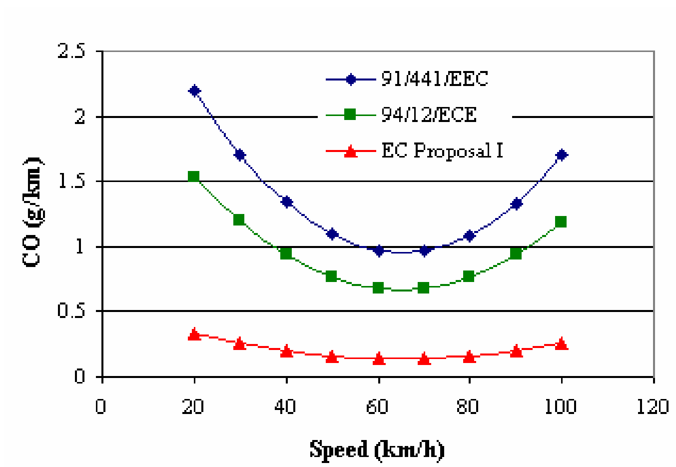

Figure 2. Emission factors for CO and cylinder capacity > 2.0 l, obtained by using COPERT II model.

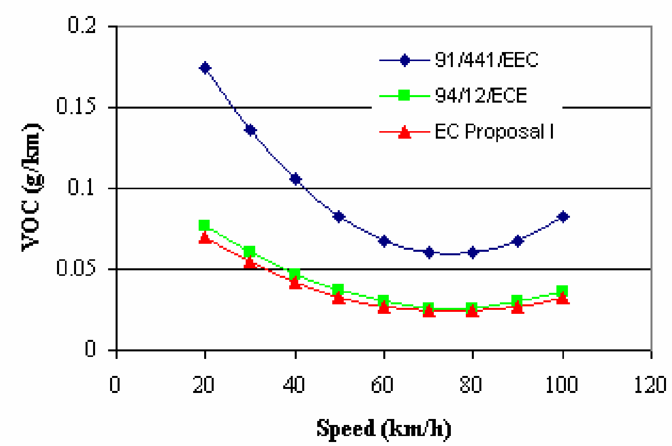

Figure 3. Emission factors for VOC and cylinder capacity > 2.0 l, obtained by using COPERT II model.

The Fig. (4), Fig. (5) and Fig. (6) show total emission for NO_x, CO and VOC in Zuzu Angel tunnel and the Fig. (7) to Fig. (12) show total emission of pollutants investigated in Rebouças tunnel. The contributions of the total NO_x, CO and VOC emissions in each gallery of the tunnels were calculated separately. In this work for urban driving condition of means speeds in the tunnels were 60 km/h in the Zuzu Angel and 40 km/h in the Rebouças. The total emissions compute in units of mass of pollutant was obtained by: *Total emission* [g] = *Number of the vehicle* × *Emission factors* [g/km] × *Length tunnel* [km].

The results showed that a reduction occurred of the EF factors for NOx, CO and VOC for vehicles categories 91/441/EEC, 94/12/ECE and EC Proposal I and cylinder capacity < 1.4 l, Tab. (7), Tab. (8) and Tab. (9), respectively and cylinder capacity 2.0 l, Fig. (1), Fig. (2) and Fig (3), respectively. However, due the largest number of vehicles in those categories contributed to a high emission of the investigated pollutants in Zuzu Angel and Rebouças tunnels.

The results showed high CO emissions in both tunnels. For example, in Zuzu Angel tunnel on 10 June, Barra / Gávea direction the total emission was 48804.16 (g), Fig. (5). The vehicle fleet between 1971 -1990 contribute with 30.58 % (14922.66g) of the total emission CO, although constitute 2.41 % of the gasoline vehicle distribution in Zuzu Angel tunnel. In the Rebouças tunnel on 30 June, Lagoa / São Cristóvão direction the total emissions was 200357.70 g, Fig. (9). The vehicle fleet between 1971-1990 contribute with 44.34 % (88834.23 g) of the total emission CO although constitute 3.78 % of the gasoline vehicle distribution in Rebouças tunnel. The results showed this behavior are similar in both tunnels, in the other investigated days.

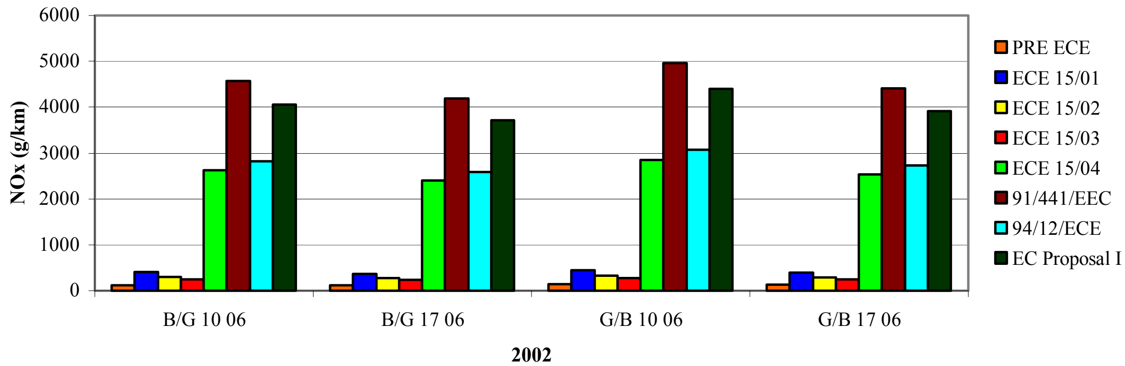

Figure 4. Total emission (24 hour) of the NO_x in the Zuzu Angel tunnel, Barra / Gávea (B/G) direction and Gávea / Barra direction (G/B) and cylinder capacities: < 1.4 l, 1.4 – 2.0 l and > 2.0 l.

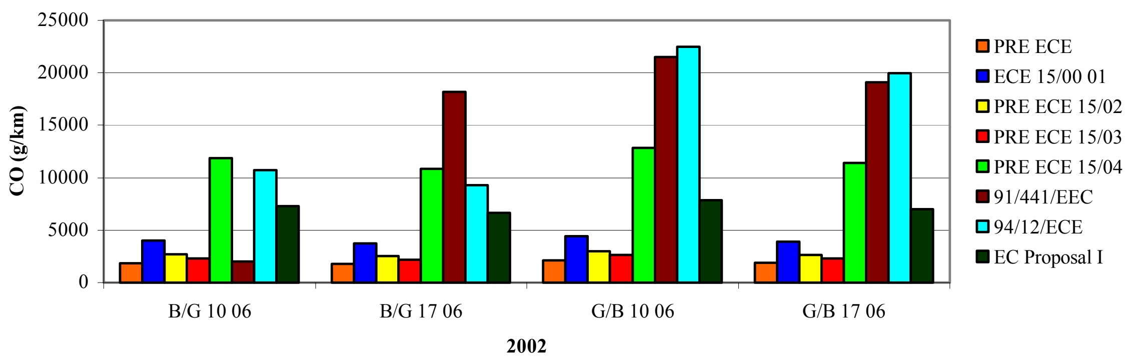

Figure 5. Total emission (24 hour) of the CO in the Zuzu Angel tunnel, Barra / Gávea (B/G) and Gávea / Barra direction (G/B) and cylinder capacities: < 1.4 l, 1.4 – 2.0 l and > 2.0 l.

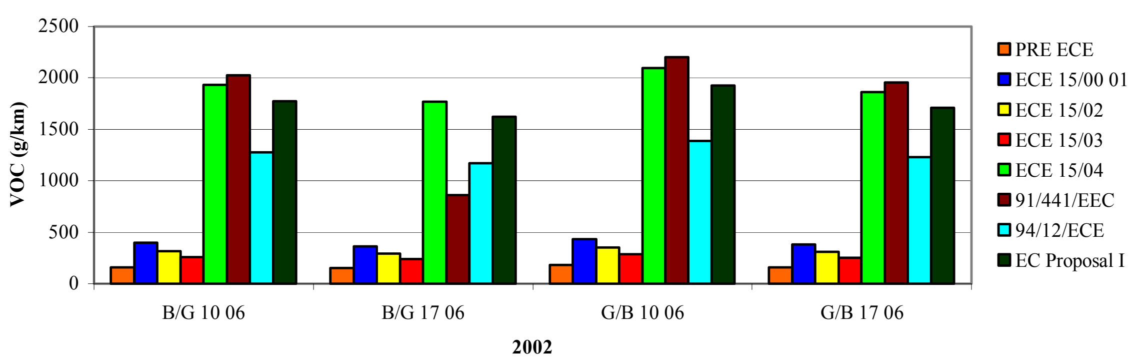

Figure 6. Total emission (24 hour) of the CO in the Zuzu Angel tunnel, Barra / Gávea (B/G) direction and Gávea / Barra direction (G/B) and cylinder capacities: < 1.4 l, 1.4 – 2.0 l and > 2.0 l.

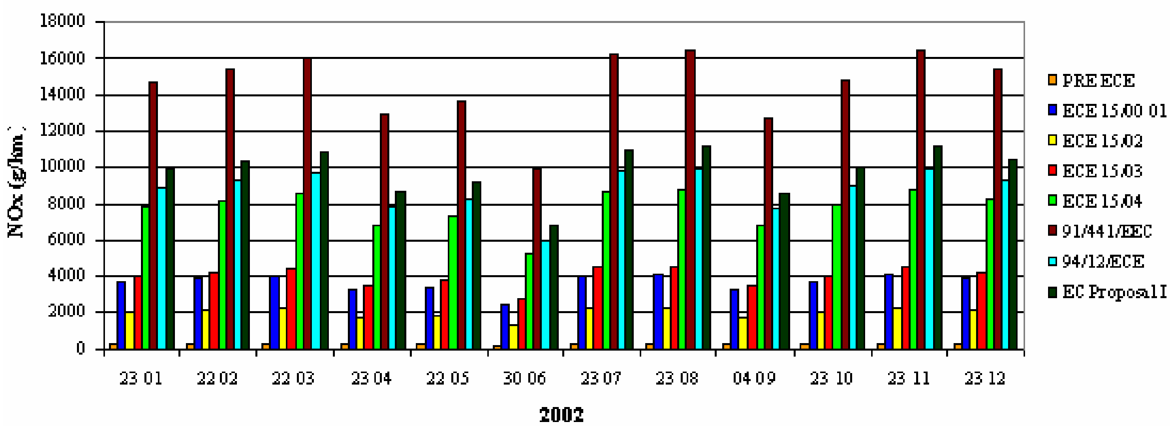

Figure 7. NO_x total emission (24 hour) in the Rebouças tunnel, Lagoa / São Cristóvão direction and engine capacities: < 1.4 l, 1.4 – 2.0 l and > 2.0 l.

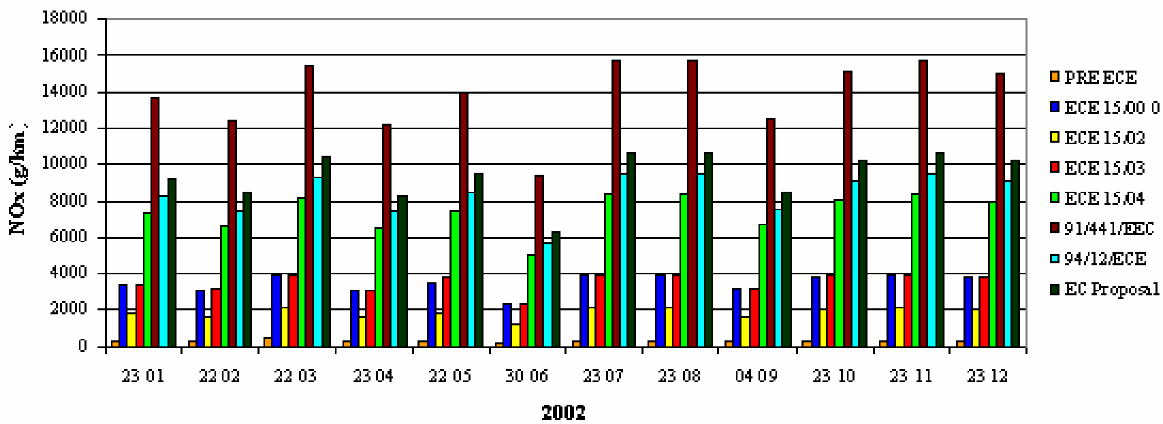

Figure 8. NO_x total emission (24 hour) in the Rebouças tunnel, São Cristóvão / Lagoa direction and engine capacities: < 1.4 l, 1.4 – 2.0 l and > 2.0 l.

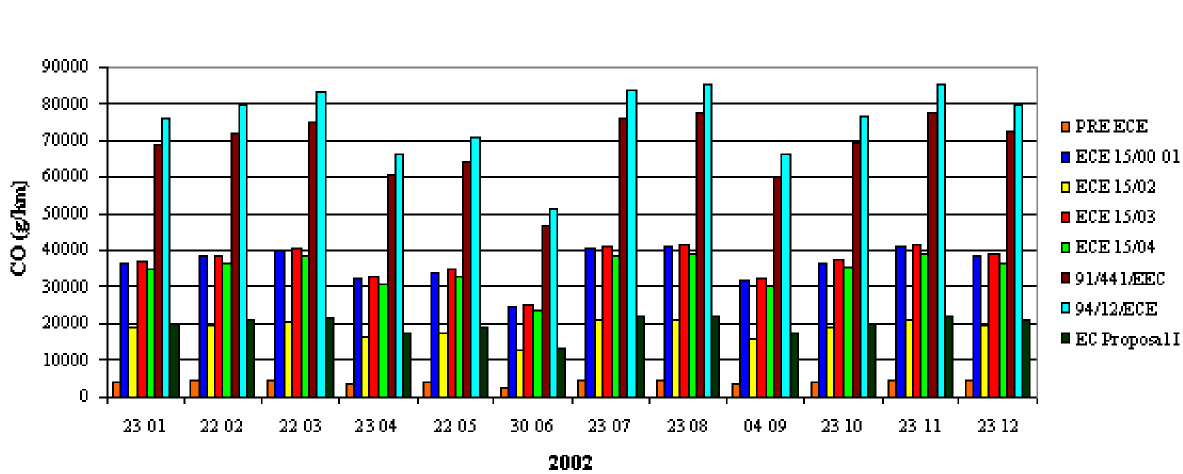

Figure 9. CO total emission (24 hour) in the Rebouças tunnel, Lagoa / São Cristóvão direction and engine capacities: < 1.4 l, 1.4 – 2.0 l and > 2.0 l.

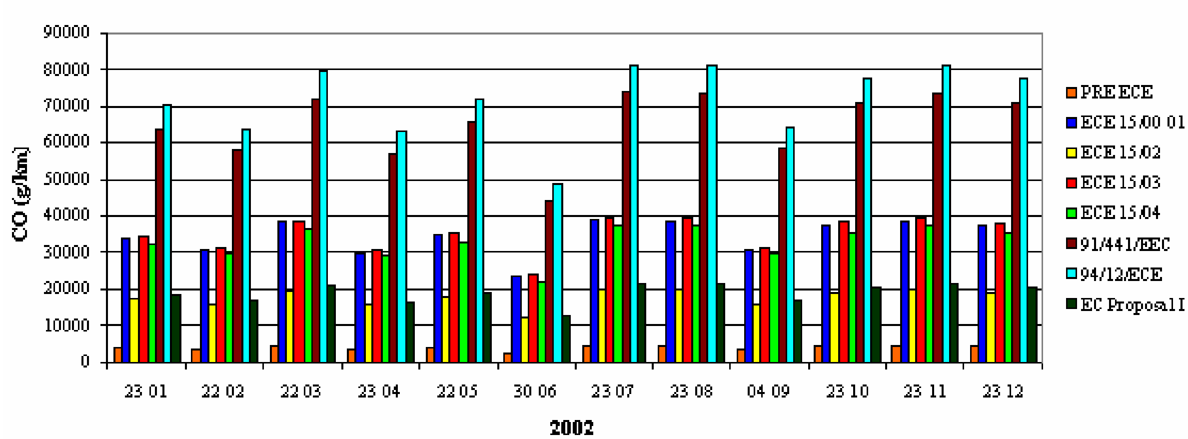

Figure 10. CO total emission (24 hour) in the Rebouças tunnel, São Cristóvão / Lagoa direction and engine capacities: < 1.4 l, 1.4 – 2.0 l and > 2.0 l.

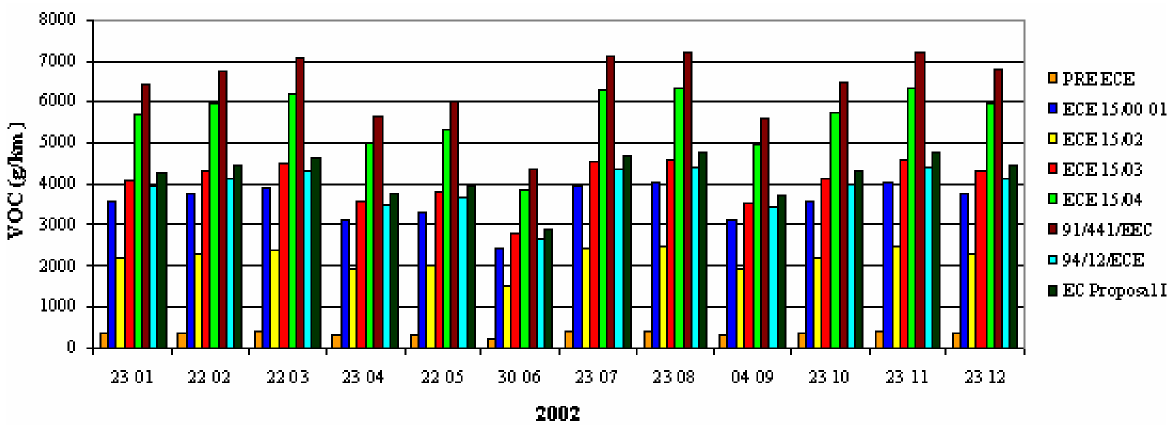

Figure 11. VOC total emission (24 hour) in the Rebouças tunnel, Lagoa / São Cristóvão direction and engine capacities: < 1.4 l, 1.4 – 2.0 l and > 2.0 l.

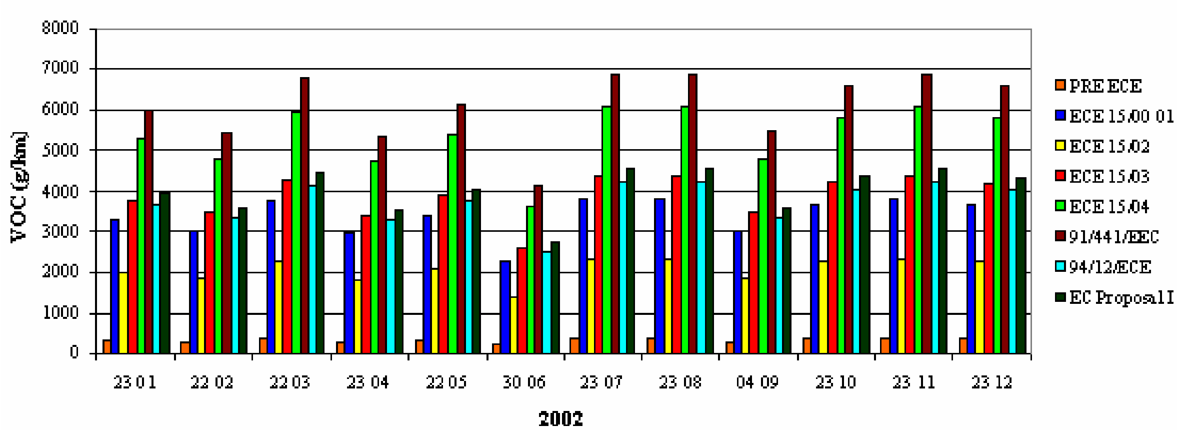

Figure 12. VOC total emission (24 hour) in the Rebouças tunnel, São Cristóvão / Lagoa direction and engine capacities: < 1.4 l, 1.4 – 2.0 l and > 2.0 l.

5. Conclusions

The values of the emission factors for NO_x, CO and VOC depend mainly on the vehicle category, the age distribution of the vehicles, the fuel properties, the presence of catalytic converter, the presence of fuel injection and on the climate conditions. In this work it was used the COPERT II model for estimating these EF. For evaluating the accuracy of the applied methodology, a comparison with measurement data in the Zuzu Angel and Rebouças tunnels was necessary.

Total emissions of air pollutants from motor vehicles depend on the number of vehicles on the tunnel. The improvement of vehicles with the inclusion of catalytic converters and fuel injection systems lead to a reduction of emissions of NO_x, CO and VOC. However, vehicle fleet and kilometers traveled continue to increases each year. Therefore, the tendency for air pollution from mobile sources is to increase overtime.

In our modeling results, for better relating vehicle age and emission control (presence of the catalytic converter) it is necessary to improve the information in the case of the 91/441/EEC category (1991-1996). This is due to fact that in the Brazilian legislation the catalyst and the fuel injection systems were not obligatory at that time.

There are many reasons for high CO emissions in road tunnels, including incomplete fuel combustion, due to poor vehicle maintenance, and vehicle age. A car emitting high levels of carbon monoxide may have an improper air/fuel mixture, a dirty air filter, a stuck choke, or a broken air pump or control valve.

As a recommendation for future research, the evaluation of the emission factors in an hourly basis should be investigated, taking into account that the velocity within the tunnel varies along the day.

6. Acknowledgement

The authors acknowledge the contributions of Dr. José Manoel Oreiro Fernandes, Manager 3 DVE/SMTR, Dr. Rui Moreira Ribeiro Filho, Manager of the C.C.O/C.V.E., and the students of PUC-Rio Rodrigro Freitas Barbosa and Thiago Gonçalves Ledo. The authors acknowledge support from CNPq.

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