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CONTINUOUS MONITORING OF VEHICULAR EMISSIONS FROM THE ACTIVE FLEET IN REBOUÇAS TUNNEL: A LONG-TERM STUDY

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Resumo

Tendo como foco principal a avaliação do impacto atmosférico associado à frota circulante local, o presente artigo sumaria os principais resultados do estudo de monitoramento de emissões veiculares conduzido no Túnel Rebouças, a partir de dados rotineiramente coletados de uma estação automática interna, operando desde 2002. Este trabalho, patrocinado pela PETROBRAS e contando também com suporte técnico e logístico por parte da administração do Túnel, integra o escopo de um projeto de P&D de longo-prazo, em uma iniciativa de multi-parceria sob a coordenação do CENPES, cujo objetivo central é prover a caracterização do impacto na qualidade do ar associado ao uso de combustíveis veiculares na atmosfera urbana. A escolha do Túnel Rebouças se justifica por sua importância em termos de escoamento do trânsito (cerca de 190.000 veículos por dia, em média) e pela extensão física da galeria em que se localiza a estação de monitoramento (2840m).Em última instância, o estudo conduzido no Rebouças tem por foco contribuir para um melhor e mais profundo entendimento a respeito das emissões atmosféricas da frota circulante local, com desdobramentos e ganhos em termos de compreensão da dinâmica das fontes locais de poluição do ar na Região Metropolitana do Rio de Janeiro.

Abstract

Continuous monitoring of atmospheric pollutants is being carried out in Rebouças Tunnel under the sponsorship of PETROBRAS, the major oil company in Brazil. This paper presents and summarizes the main results of the campaigns that have been going on since 2002, in the effort to build a more accurate assessment of the “real world” vehicular emissions coming from the current local fleet. The ultimate goal is to improve the knowledge of local air pollution source dynamics by upgrading the estimates of mobile sources contributing to atmospheric impact in Rio de Janeiro Metropolitan Area (RJMA). The choice of Tunnel Rebouças as the monitoring spot in Rio is justified by its relevance as a local transportation artery. Rebouças is the largest urban tunnel in RJMA, with a 2840 m length pathway split into two galleries, and is an intense traffic artery in Rio linking the South and North areas of the city. It is composed of two bores, with three lanes per bore, in which typical traffic density is relatively flat with time and roughly 190.000 vehicles pass on a per day basis. The local fleet is predominantly composed of light duty vehicles (LDV), ca 95%. From a local station placed inside the longest gallery (2040m length) in the tunnel, the four criteria pollutants - carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2) and PM-10, together with total hydrocarbons/methane (THC/CH_4), have been continuously monitored on a routine basis since 2002. Additional support to the present study was graciously granted by the tunnel management, including power supply for the equipment, granting access to the operational facilities as deemed necessary and making available important information on automatic traffic counting. The present study integrates all these parameters, correlating concentration profiles, ratios between the main pollutants and CO and traffic information.

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1. Introduction

According to the latest official sensus (IBGE,2006) approximately 12 million people live in the Metropolitan Area of Rio de Janeiro (RJMA), encompassing 20 municipalities, distributed over an area of 5,645 km^2. The RJMA is the 19^{th} of top 20 megacities in the world (City population,2006).

Rio de Janeiro, the Capital of Rio de Janeiro State, is located at $22^0$54’10’’ LAT S and $43^0$12’27’’LON W, has a population of 6.094.183 habitants distributed over an area of 1.182 km^2 suffers from severe air pollution problems, just like São Paulo, the first urban centre in Brazil, and other megacities[1] in the world. In the particular case of Rio the local air pollution dynamics, apart from the undoubted contributions of atmospheric emissions, is heavily influenced by a combination of terrain complexity, wind circulation and climate features, such as intense sun light and high average surface temperature levels, tending to favor photochemical transformations in the atmosphere. This scenario is consistent with registered violations of NAAQS (CONAMA 003,1990), (FEEMA, 2006), specially for inhalable particles (PM_{10}).

At the time the study started Rio de Janeiro City represented the second largest running fleet in Brazil: roughly 1,5 million passenger cars and commercial vehicles (IBGE,2006), (DETRANRJ, 2006), (CET Rio,2003) being composed of approximately 82% LDV (Light-Duty Vehicles), fired mostly by a mixture of motor gasoline and ethanol, 12% (buses and trucks) HDV (Heavy Duty Vehicles) running on diesel and 6% motorcycles. According to the most recent available official emission inventory (FEEMA,2006), approximately 76% of the total air pollution load of CO, SO_2, NOx and PM-10 are direct contributions of the mobile sources. In the case of CO, 98% comes from vehicles. Another important issue to be considered in terms of local environmental policies is the age of the car fleet: according to the traffic authorities in Rio (DETRAN RJ,2006), over 50% of the running fleet is above 10 years old. These figures, despite the obvious scarcity of reliable information on atmospheric emissions and the intrinsic lack of accuracy of the data available, reinforce the importance of an I&M vehicular program provided on a regular basis to support and subsidy the elaboration of local sound and cost-effective air quality management and control policies.

Aiming to subsidy the construction of validated databank on vehicular emissions from the “real world” in Rio de Janeiro, an R&D Project was started-off in 2002, based upon the continuous monitoring of the concentration levels for the main criteria pollutants, such as carbon monoxide (CO), nitrogen oxide (NOx), sulfur dioxide (SO_2), inhalable particles (PM_{10}), together with the non-regulated HCT(total hydrocarbons, methane included, not discussed in the present paper), known for their close association with the status of the active fleet. The main goal of the study, fully sponsored by PETROBRAS, was to raise data to support the assessment of important features, such as fleet turn-over, changes in the local fuel chart (such as the impact of compressed natural gas, CNG, and flex-fuel used in Rio in the LDV fleet), thus establishing the preliminary technical and experimental dataset for some inferences on the local fleet emissions/ emission rates. A confined environment such as an urban tunnel granted the necessary minimization of the external or environmental variables, such as solar radiation, wet or dry precipitation, wind advection etc, thus providing the scenario for the characterization of an “average” local vehicular emission profile.

Given its relevance as an urban transportation artery and the prevailing contribution of LDV in the local fleet (roughly 95% of it) and the tunnel length (2.840 m) Rebouças Tunnel was chosen as the prime monitoring site for the study. A complete monitoring station was installed inside the gallery connecting Cosme Velho to Rio Comprido, or respectively the South and North wards of Rio de Janeiro. Figure 2 illustrates an schematic plot of these main features.

The initial time frame for the whole study was two years of maximum duration. Nevertheless given the scarcity of information available, decision was taken to “stretch” the project timing and start-up a second monitoring location, thus allowing a more comprehensive monitoring of the emissions. The Rebouças Tunnel Vehicular Emissions Study encompasses 4 years of continuous emissions monitoring during which in the last 6 months two sampling locations were simultaneously operated. Additional campaigns (not shown), which were tailor made to provide a comprehensive assessment of reactive ozone precursors emitted by the active fleet in Rio, were tackled throughout the Rio de Janeiro screening campaigns and VOC characterization studies (Grosjean et al, 2003), (Moreira et al, 2005), (CENPES, 2004,2005), in a series of location sites which also included Rebouças Tunnel.

2. Evolution of the Vehicular Fleet on a Wide Perspective

2.1. International Scenario

Roughly in the last 10 years a very intensive and quick economic growth process had a counterpart in terms of pronounced increase in the vehicular fleet worldwide. As a rule, passenger cars were the vehicle category to exhibit the most pronounced growth rates in the period.

Figure 1 illustrates the data for the top 10 vehicular fleets in the world, in the period bracketing 1999 to 2002, encompassing roughly 67% of the world fleet, which was at that time about 813 million vehicles. Presently Brazil ranks 9^{th} in the world, representing approximately 3% of the world fleet, as opposed to the USA, ranking 1^{st} and representing ca 28% of the total vehicles of the world. These impressive figures justify *per si* the massive importance of the mobile sources in the management of air pollution dynamics at the world level.

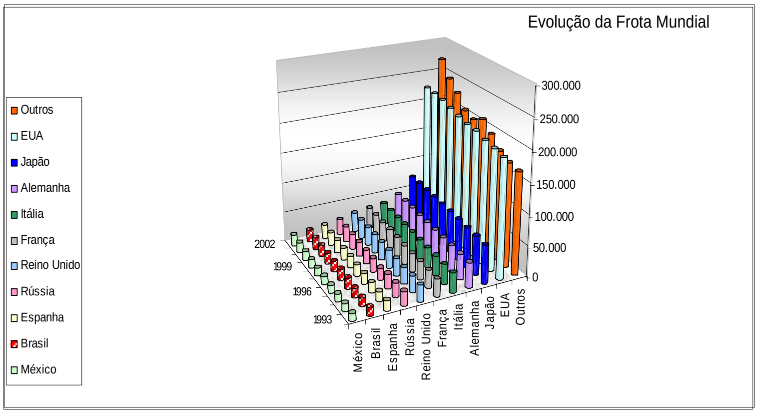

Figure 1. Growth of the world vehicular fleet up to 2002, detaching the top 10 countries- ANFAVEA (2005)

2.2. National and Local Fleets

According to DENATRAN (DENATRAN,2006) the domestic Brazilian fleet (including both LDV and HDV) was in 2003 of 36,658,501 vehicles. Of these 20,083, 423 or roughly 54.8% were concentrated in the SE region of Brazil.

Cities like São Paulo, with 4,382, 907 vehicles (12 % of the national fleet) and Rio de Janeiro, with 1,517,276 vehicles (4 % of the Brazilian fleet) concentrated a little less than 17% of the total national fleet.

Table 1 summarizes the most relevant information regarding local fleet distribution in Rio and São Paulo as well as the respective states; Table 2 illustrates the active fleet stratification for Rio de Janeiro Municipality for the most important vehicle categories.

Table 1. São Paulo and Rio de Janeiro local fleets

Geographic Basis (a)	**Vehicle Fleet**	
	Number (b)	**%** (c)
Rio de Janeiro State	2,894,882	8
Rio de Janeiro City	1,517,276	4
São Paulo State	12,665,366	35
São Paulo City	4,382,907	12

(a) information shown both at the State and Municipality levels
(b) fleet includes both HDV and LDV (Heavy and Light Duty Vehicles) for the year of 2003
(c) individual percent contribution to the National HDV + LDV fleet

Table 2. Fleet distribution for Rio de Janeiro City

Vehicle Category		**Percent Contribution** (a)
LDV	(b)	82.6
TRUCKS	(c)	10.3
BUSES	(d)	1.4
MOTORCYCLES	(e)	5.5
All other categories		0,2

(a)Percent contribution per vehicle category considering the Rio de Janeiro Municipality for the year of 2003;
(b) Light-Duty-Vehicles were assumed to include passenger cars and taxis; fired by GASOHOL (a mixture of ca 75% vol motor gasoline and 25% vol anhydrous ethanol), which represents roughly 76,6% for the local LDV fleet; CNG (Compressed Natural Gas, a regulated mixture of C1 to C3) contributing to 3,0% of the LDV fleet in Rio; HYDRATED ETHANOL (a mixture of ca 95% vol ETHANOl and 5% water) equivalent to 14,5.% of the light duty cars and the remaining fired by the "FLEX FUEL" (a mixture of motor gasoline and ethanol in various proportions)
(c) This category comprises the local contribution of trucks of various sizes and weights, tractors and tows;
(d)Micro buses included;
(e)All 2T engines included.

3. Rebouças Tunnel Study

3.1. Benefits of A Pioneer Study in Brazil

The advantage of sampling inside an urban tunnel is the more realistic picture of the local fleet profile, given the absence or minimization of external perturbations, such as atmospheric scavenging processes, that may interfere by changing the profile of the local primary emissions. Another important advantage of this type of study, as opposed to sampling emissions directly from a chassis dynamometer facility, for instance, is the adherence of the measured concentration levels to the emissions coming from the "real world" active fleet, given its current status and actual maintenance conditions.

To our knowledge the Rebouças Emission Monitoring Study has no similar or comparable study having been carried out in Brazil up top now, given both its duration in time and level of detail. It is worth to mention that not only in Brazil but even in the international scenario such a comprehensive assessment of vehicular emissions is not a routine job, given mainly the problems of logistics, associated costs, safety and exposure issues. Early references of studies carried out in Brazil target a limited subset of chemical species (formaldehyde and acetaldehyde) being measured by a short period of time, such as in the works of Tanner (tanner et al, 1988) and Carvalho (de Carvalho, 1992). More recently in São Paulo Sanchez-Ccoyllo (Sanchez-Ccoyllo, 2002) and Pretto (Pretto, 2005) cover some aspects of short-term measurements carried out respectively at 9 de Julho Tunnel and Janio Quadros as well as Maria Maluf tunnels located at MASP. In the U.S., Schattanek (Schattanek et al, 2004) describe a long-term experience in terms of CO monitoring carried out in Ted Williams Tunnel (Boston, MA).

3.2. Background Information

Rebouças Tunnel opened to commercial traffic on September 3rd 1967, linking the North and South wards of Rio de Janeiro City, and is managed by the Municipal Secretary of Transportation, through its branch called Coordination of Special Traffic Arteries or 1st DVE, as in the Portuguese acronym.

Figure 2 illustrates the Tunnel schematic drawing, detaching Substation Number 4 (SB 4) and also Substation Number 3 (SB 3), both located on Gallery L1. Galleries L1 and R1, as shown, are part of the bore connecting the South to the North areas of Rio, with the traffic flowing northwards. Inside SB4 is located our main monitoring site for the present study, in operation since 2002, and is the core of the present paper. Inside SB3 was placed the second monitoring station, started off in the second semester of 2005, also under the sponsorship of this study. The traffic in Gallery L2, located in the same bore as R2, flows in the opposite direction of L1, from the North towards the South

The original tunnel Project was conceived for a traffic volume of approximately 80,000 vehicles/day, with two lanes per bore for the traffic flow, being the third lane reserved as an emergency lane.It is important to mention that currently the traffic flow is roughly 2.3 times the design capacity, that is, the number of vehicles per day ranges from 180 to 190,000. All the three lanes per bore are currently used for the traffic flow, which seems to be very close to the saturation limits for the tunnel. As a natural consequence of that, traffic congestion occurs in both bores during a substantial fraction of the working hours.

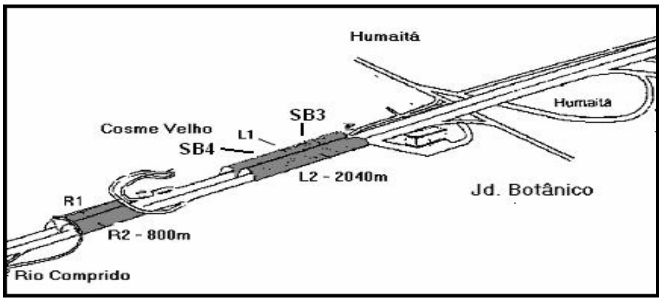

Figure 2: Rebouças Tunnel schematic drawing showing SB4 and SB3.

As shown in Figure 2, the two main galleries are L1 (northwards) and L2 (southwards) with an approximate length each of 2,040 m, linking Humaitá to Cosme Velho. There are also two secondary galleries, R1 (northwards) and R2 (southwards), connecting Cosme Velho to Rio Comprido, with 800 m length each roughly. In the main gallery for the traffic flowing northwards (L1) , the second monitoring station is located in SB3, roughly 500 m from L1 entrance.

The main monitoring station, located in SB4, is roughly 1,000 apart from SB3 or 1,500 m distant from L1 entrance. The tunnel cross section is 81 m^2 in both bores. In L1, there is a positive inclination of approximately 2%. This fact, together with the longer length apart from the entrance and the availability of more space in which the monitoring equipment could be installed, provided the necessary justification for choosing SB4 as the primary monitoring site. The preparation of SB4 included the manufacturing of a special container, in which the equipments were sheltered and conditioned. Prior to the final physical allocation of the monitors in SB4, power supply points were installed and prepared by the Tunnel management, that also granted it for free. The tunnel ventilation system is currently composed of 78 fans lumped in groups. The original project included the intake of fresh, external air from the entrance of the tunnel and its supply into the galleries from the tunnel ceiling, thus granting the flow of local background air onto the vehicles inside Rebouças. This project was much similar to the ventilation systems commonly adopted in the U.S., but unfortunately it granted no financial support. Up to this date, the tunnel ventilation system installed is composed of the fans, lodged close to the tunnel ceiling, that have the function of pushing air towards the traffic flow. Gallery L1 is considered to be the most critical in terms of pollution load and currently operates with 55 fans throughout its whole length.

4. Monitoring Methodology and Data Storage

The pollutants were sampled inside the Tunnel, in a continuous monitoring station installed inside SB4, recording concentration levels of CO, NOx, SO_2, PM_{10} (regulated) and also total hydrocarbons (non-criteria).
CO concentration levels were measured by infrared spectroscopy (SERES Model CO2000); NOx (NO+NO2) were measured by a chemiluminescence (SERES Model NO-NOX2000); SO2 was analyzed by a Ultra-Violet fluorescence (SERES Model SF2000). PM_{10} was measured resorting to a β- attenuation monitor (manufactured by Andersen instruments).

Calibrations of the continuous analyzers (NO_x, CO and SO_2) involved the use of an API Model 700 multicalibrator together with a cylinder of NIST-traceable certified gas mixture (51,5 ppm NO, 5130ppm CO and 51,5 ppm SO_2 in nitrogen), manufactured by Scott-Marrin.

Data storage was provided by Datalogger, manufactured by Campbell model CR10X.

On average once to twice a week the station was visited by the field technician, in order to take the necessary inspection and maintenance actions, download the data and proceed the required zero/span calibration/verification routines *in locu*. More sophisticated interventions such multicalibration, drift, linearity checking and equipment cleansing required to take each monitor to an external facility, in which the procedures would be executed in a more convenient way. One of the most serious problems was the lack of spare or back-up at the time for the equipments in operation; once the equipment was being checked or out for repair there would unfortunately be no spare or substitution, thus justifying the elevated percent of lags or blanks in our monitoring time series.

Further enhacements and upgradings in the tunnel operational procedures, performed quite recently, included the data remote transmission via modem to our CENPES personal computers, thus granting more convenient scheduling of field routine operations for the field technical team.

Despite the intrinsic difficulties in the logistics of operating the station inside the Tunnel, efforts were dedicated to following strict quality control and assurance policies, which were inspired by USEPA (USEPA, 1998), in its CFR 40.

5. Main Results

Mainly due to space limitations, the present paper will focus on some relevant results for the Rebouças Vehicular Emissions Monitoring Study- Phase I, such as composite averages for the traffic flux, CO concentration values and criteria gas-phase pollutant ratios to CO in the period of 2002-2005.

5.1. Daily Traffic Distribution

Figure 3 illustrates the daily hourly variations of the traffic inside Rebouças Tunnel Gallery L1, flowing northwards, all vehicle categories included. This graph is a composite plot for the average traffic counting throughout the year, bracketed only for the weekdays, weekends excluded. The values shown correspond to the 1-h average traffic flow for roughly 20 weekdays per month throughout the year, thus composing a typical day cycle. As a rule, there is very little traffic during the very late hours of the night and early hours of day, with an uptake of traffic flow approaching 06:00A.M; traffic peaks off roughly at 07:30 A.M. with a secondary peak at 05:30 P.M. In between these hours, the traffic flow profile is rather flat with time.

This procedure was repeated for each one of the three years that composed the first phase of monitoring in Rebouças. For all the three years the data show high level of constancy within 1- sigma variation levels (not show), thus suggesting that the saturation limits for the tunnel have been nearly reached. After the afternoon peak, the volume flow shows a downward trend, thus consistent with the saturation scenario.

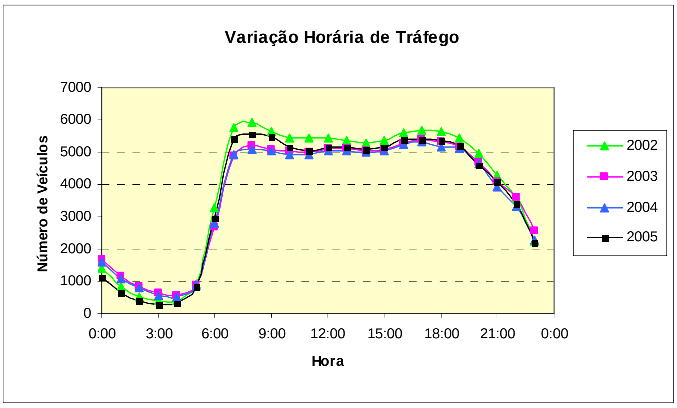

Figura 3: Hourly variations of total vehicle flow in Gallery L1 for 2002-2005

5.2. Consolidated Hourly Concentration Values for CO

Following the same approach adopted in the construction of the composite traffic flow for Rebouças, composite typical profiles were built for each pollutant for each year (not shown). In a similar fashion to what was observed for the traffic flow, the hourly variations for the pollutant concentration levels inside Gallery L1 exhibit a roughly flat profile or a rather insubstantial variation from day to day.

In terms of typical day cycles as a rule the highest concentration levels occur close to traffic peaks and the criteria pollutants show good overall correlation levels with CO, as expected, given their common combustion-bound origin, justifying the presentation of their average concentration variations or estimates based upon simple linear regressions with CO measured values. This is valid for mostly all the composite annual plots, as well for the monthly average values (not shown). Figure 4, presented below, shows the composite plot for CO average concentrations for the first phase of Rebouças study, obtained as detailed in the previous topic.

On average, CO 1-h concentration levels ranged from 10 to roughly 55 ppmv throughout the 4 year monitoring period. Peak concentration values occurred due to intense traffic hours, as consistent with traffic flow patterns, mainly in the morning and early evening rush hours. These relatively high values are consistent with the pollutant formation process, mainly due to the partial oxidation or incomplete fuel combustion, which is heavily influenced by the very intense traffic and its flow patterns inside Rebouças Tunnel. Factors such as cold start, de-accelerations, low speed levels, intense accelerations etc tend to maximize potential CO emissions due to average rich-fuel burning conditions.

The concentration levels are also a reflex of the location of the monitoring station (about 1.5 km inside the uphill tunnel gallery, thus potentially maximizing the emissions).

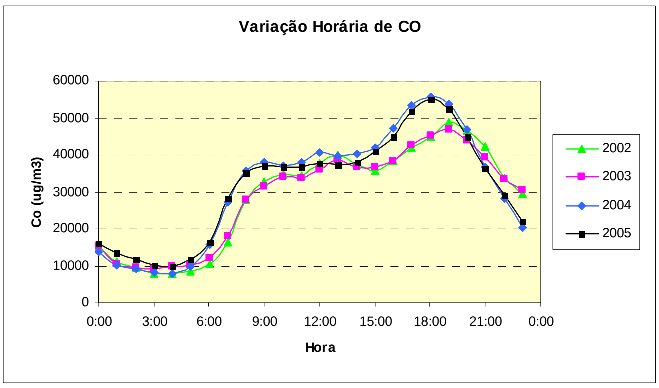

Figure 4: CO 1h composite average concentrations for 2002-2005

5.3. Pollutant Ratios to CO

Mostly for all the criteria pollutants measured the correlation coefficient values (r^2) obtained in the regressions with CO ranged roughly from about the 80 to roughly the 90% levels in the period of 2002 to 2005.

On average SO_2 and PM_{10} tend to present lower values of r^2 levels, but still ranging above the 75% level. With one clear exception, which are the observations of SO_2 in 2003, being currently re-assessed in a more stringent way for quality control purposes.

Figures 5and 6 present the average composite ratios to CO for NO and SO_2 , for the same period. It is important to mention that on average for all the pollutants measured there were no substantial decreases in the recorded concentration levels, within 1-sigma variation limits, for the period of observations.

NO concentration levels ranged from less than 1 ppm to about 4 ppm and this form is by far the dominant for nitrogen oxides (NOx) found in the tunnel, accounting for more than 90% of the sum of NO plus NO_2.

As shown in the referred plot, the NO correlation levels with CO ranged from $0.77<r^2<0.87$ for the whole Rebouças Phase I , thus enabling simple estimates of NO emission levels based upon CO measures.

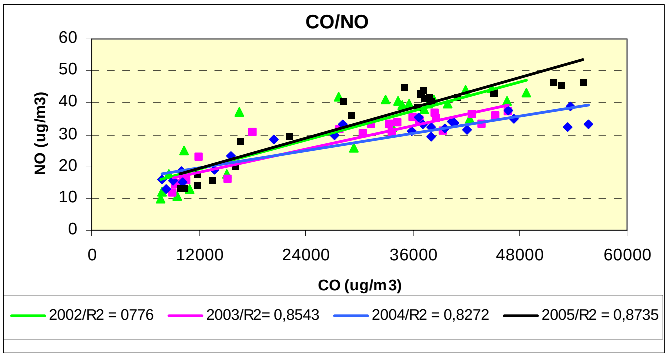

Figure 5. NO/CO ratios in 2002- 2005

Sulfur oxides in Rebouças were measured as SO_2 and showed a concentration variation range within the limits of 55 to roughly 140 ppb for the whole Phase I Study. The prevailing formation process is through the combustion of fuel- bound sulfur, more abundant in diesel than in the lighter motor fuels, which is consistent with a subtle lag in the observed peak values, as compared to those for CO. Nevertheless, as expected, the observed r^2 levels with respect to the concentration ratios to CO varied in compatible limits to those shown before for NO: $0.76< r^2<0.86$.

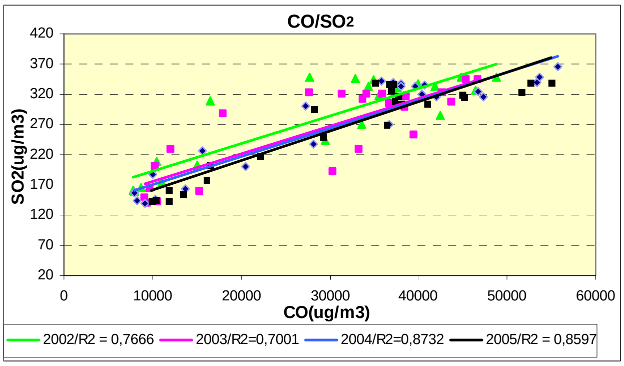

Figure 6. SO_2 /CO ratios in 2002- 2005

6. Main Conclusions up to Now

Rebouças Phase I study enabled the initial assessment for the current local active fleet emissions in Rio. The partial results up to now show good correlation levels of the main pollutants to CO, as consistent with the vehicle-bound origins of these pollutants and also the prevalence of LDV within the local fleet. The observed concentration levels for all the pollutants measured are elevated, as consistent with the intensive traffic and the elevated percentage of traffic jams inside the tunnel, together with the location of the monitoring station in SB4 (that tend to double the observed concentration levels on average, as compared to the more recent SB3 concentration information) (not shown).

Unfortunately up to now not very substantial decreases could be perceived in the CO averages recorded within the monitoring period, despite the substantial increase in the participation of cleaner fuel options, such as CNG, that is regulated by Regulation CONAMA 291 (CONAMA, 2001). It is worth to mention that Rio de Janeiro stands for roughly 40 % of the national CNG fleet (Gas Brasil, 2005). Possible explanations for the unnoticed decreases in the CO concentration levels may be a combination of factors such as the limited time coverage of the present study (4 years in a row, thus not enabling the assessment of substantial local fleet turnover, with direct reflects on the overall emission rates), together with the scrappage or deterioration of the older vehicles (high emitters) composing the local fleet. Another very important factor that unequivocally contributes to the offset of the expected decrease in the observed emissions levels is the contribution of the (unwanted) presence of unofficial fuel converter kits (the so called "pirate kits") that allow the burning of gas by adapted Otto cycle engines running in uncontrolled conditions. The net effect of the latter is not benefiting at all from the more environmental friendly qualities of the CNG fuel, as consistent with the results of emission tests run on chassis dynamometers (CENPES,2006).

7. Acknowledgments

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8. References

ANFAVEA, 2005 – http://www.anfavea.com.br/Index.html. Last access in January, 2006

CENPES Project Number 60.14.14 – Vehicular Reactivity Characterization - Internal Reports, **2006**. Vehicle Emission Tests for CNG –2005. Unpublished data.

CENPES Project Number 60.14.13- Atmospheric Reactivity of VOC's Internal Reports- Rio de Janeiro Survey- Phase 2- VOC Characterization Study carried out in 2004/2005. Unpublished data;

CET Rio – Rio de Janeiro Traffic Engineering Company - Internal Reports, **2003**; Rio de Janeiro, RJ, Brazil. Available from the institution upon request.

City Population - http://www.citypopulation.de/World.html (accessed January/2006)

CONAMA 003/90, de 28/06/1990 – see http://www.ibama.gov.br/licenciamento/index.php (accessed January/2006)

CONAMA 291/01 see http://www.ibama.gov.br/proconve/divs/res_291_01_GasNaturalAutom.PDF. Last access in January, 2006

DENATRAN- Brazilian Federal Traffic Authority – see www.denatran.gov.br/frota.htm. last access in Januray, 2006.

DETRAN RJ – Rio de Janeiro State Traffic Authority – see http://www.detran.rj.gov.br/ (accessed January/2006)

FEEMA – State Environmental Agency - Fundação Estadual de Engenharia do Meio Ambiente – Rio de Janeiro State Environmental Agency - see http://www.feema.rj.gov.br (accessed January/2006)

GAS BRASIL, 2005 see http://www.gasbrasil.com.br/mercado/gnv/estatistica_gnv.asp. Last access in January, 2006

Grosjean E., Grosjean, D., Rasmussen, R., Moreira, L., Moreira, A. Speciated VOC in Rio de Janeiro Highway Tunnels and Parking Garages. Paper # 69181 presented at A&WMA 96th Annual Meeting, **2003.**

IBGE – Brazilian Institute of Geography and Statistics – see http://www.ibge.gov.br/cidadesat/ (accessed January/2006)

Moreira, A.; Almeida, J.C., Minho, A; Grosjean, D.; Grosjean, E.; Rasmussen, R. – Updating the Profile of Speciated VOC in Rio de Janeiro Metropoitan Area to Assess Ozone Production.Paper # 1091, presented at A&WMA 98th Annual Meeting, **2005**.

Pretto, A. Ph.D. Dissertation. Universidade de São Paulo, Brasil, **2005.**

Tanner, R. L.; Miguel, A. H.; de Andrade, J. B.; Gaffney, J. S; Streit, G. E.; Atmospheric Chemistry of Aldehydes: Enhanced Peroxyacetyl Nitrate Formation from Ethanol Fueled Vehicular Emissions. *Environment Science and Technology*, 22,1026.1988.

Sanchez-Ccoyolllo, O.R.; Ph.D. Dissertation. Universidade de São Paulo, Brasil, 2002.

Schattanek, G., Wan, P, Kasprak A. Paper # 331, presented 97th AWMA Annual Meeting 2004.

USEPA – United States Environmental Protection Agency - *Code of Federal Regulations- CFR 40* – Parts 50 to 51/ Parts 53 to 59 -Office of the Federal Register National Archives and Record Administration, **1998**. 512 p/ 375 p.