LPAE – LABORATORY OF EXPERIMENTAL ATMOSPHERIC POLLUTION

SCHOOL OF MEDICINE OF SAO PAULO UNIVERSITY

ESTAPLAN PLANEJAMENTO E CONSULTORIA LTDA

IMPACT FILTERS SYSTEM
SABERTEC

EVALUATION OF PERFORMANCE IN ACTUAL USAGE INSTALLED IN URBAN BUS

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Summary

1. Introduction

Inhabitants in big urban centers have no choice but to inhale suspended pollutants in the atmosphere, which can vary a lot in terms of composition and environmental concentration, causing different effects on that population's health.

The pollution caused by the particulate matter refers to a mix of solid or liquid particles suspended in the air, which have a variety of form, composition and origin. By default, in the particulate matter, from now on called only as PM, 3 fractions are considered: coarse, fine and ultra fine. The coarse fraction is composed by particles with an aerodynamic diameter superior to 2.5µm and are generated from the ground or any other material on the surface. In cities with high-density traffic, a significant fraction of the coarse particle is produced by the friction between the vehicles' tires and the asphalt on the street, containing elements from both the pavement and the rubber from the tires. The fine particles, those with aerodynamic diameter inferior to 2.5µm (PM2.5) are generated, in general, by the combustion process generated by motor sources, industries or by biomass burning. The PM2.5 contains primary particles directly produced by the emission sources, as well as secondary particles (especially sulfates and nitrates), generated by the process of gas to particle conversion from sulfur oxide and nitrogen oxide. They are part of the PM2.5 coal particles produced by the combustion of fossil fuels, that have different elements and compounds adsorbed into their surfaces, such as heavy metals and hydro carbonates.

According to CETESB, State Agency dedicated to the environmental management of the State of Sao Paulo, in its 2005 annual report (CETESB, 2006), 40% of the atmospheric pollution by PM, in its inhalable fraction (those with aerodynamic diameter inferior to 10 µm), 96% of the pollution by nitrogen oxides and almost 42% of the pollution by sulfur oxides are originated by vehicles emission.

Part of the oxides referred above will be transformed in PM, the so called secondary aerosols, making more 25% of the pollution concentration per inhalable PM.

Still, according to the CETESB Report, diesel vehicles constitute the major originators of the pollutants referred above in the vehicular source, with 79% of the nitrogen oxide, 19% of the sulfur oxides and 28% of inhalable PM, in relation to the total emission by all other sources combined.

This makes it clear the importance of the diesel mobile source in generating atmospheric pollution in Sao Paulo.

The action of the public politics of atmospheric emissions managers has been developing programs, such as the PROCONVE, aiming to reduce those emissions, but those actions demand a lot of time and large investments.

The possibility of defining actions in a short period of time and with low cost, capable of reducing the atmospheric emissions by diesel vehicles, becomes of evident urgency and importance of bringing, more rapidly, the reduction of environmental concentrations with the subsequent reduction of the aggravations on the population's health, in terms of morbidity and even mortality.

In that scenery, the development of an Impact Filtration System by SABERTEC, from now on called as Particulate Retainer, which allows the retention of particulate matter directly inside the vehicle's exhaust pipe (diesel or gas) before it is released into the atmosphere, can enable an environmental intervention in a short period of time, which would attend to that necessity, especially in large urban centers.

Facing that possibility, several agencies showed interest in accompanying and contributing, inside their specific areas of action, for the evaluation of the equipment, putting together a forum for discussing the topic and helping the LPAE – Laboratory of Experimental Atmospheric Pollution from the Pathology Department at the USP Medicine School, to develop and carry out the tests, being them:

- Municipal Chamber of Sao Paulo County, through the office of Councilor Aurelio Nomura.
- SPTrans – Sao Paulo Transports SA, through its Engineering Department.
- Secretary's Office of Green and Environment of Sao Paulo County.

2. Objectives

As the Particulate Retainer, referred above, is still an equipment in development to what laboratorial and experimental data that proves its efficiency is not available, and considering the nonexistence, in Brazil, of a tests protocol in the environmental legislation for its application in an actual situation, the one we have in the city's streets, it was decided to elaborate a specific experimental protocol in order to:

a) allow to simulate an actual situation of urban use in Sao Paulo

b) be done with diesel vehicles, passenger transportation bus

c) be sensitive enough to detect differences in the emissions during situations of not using and using the equipment in the bus

d) allow to estimate an order of magnitude for the emissions of fine PM, that is, to evaluate the concentration of PM in the gas discharge of the exhaust pipe relatively to using and not using the equipment in the bus

3. Materials, equipment and test procedures

3.1. Experimental procedure

In order to attend to those objectives, two reports were produced, which are found in attachments 1 and 2 of this report, concerning:

- Experimental Procedure for Tests – Prj-603: describing the protocol regarding construction and components, test methods and definition of data analysis
- Bus Lane Analysis – Test Protocol: analyzing data from vehicles used on the "Largo São Francisco – Varginha Terminal" bus lane.

In short, the structure of the Particulate Retainer will be installed on the bus' chassis. Two situations or configurations for testing will be considered: without any device and installing the device under analysis.

The test circuit, a previous defined track, will constitute the route. Three routes will be traveled by the bus, with the same configuration, with a minimum stopping interval of 15 minutes between each route, during which the bus will be kept running in slow gear. The data from the 3 routes will be, then, considered in the analysis as characteristic of that configuration.

The route will be divided in 4 sections, simulating the distance between the bus stops, while there will be a waiting time at them.

The waiting time was previously estimated, in order to adjust the test average speed when the bus will keep running in slow gear.

Each section will have a speed target, except during acceleration and slowing down.

3.2. Complementary Definitions to the Protocol

Parameters that characterize the use of passenger transporting bus in Sao Paulo County were also discussed with the participant agencies:

- distance between each successive bus stop: 300m to 500 m.
- vehicle of interest: Bus engine MB-1620, years 1996/1997.

- use of the same driver during the tests, avoiding deviation in the analysis.
- Use of a route in a controlled traffic site to avoid interference.

3.3. Construction of the circuit

With those definitions in hand and availability of the Interlagos Car Racetrack for performing the tests, it was possible to introduce the structure for the circuit as follows:

- site: part of the circle perimeter at Interlagos Car Racetrack (see attachment 3).
- the selected site is not a closed circuit. This way, the departure and the arrival being at the spot, demand traveling both ways, round trip, compelling the bus to make a maneuver at each end of the track, consuming 50 m for each one of them.
- signalized distances with a length of 400m each, done respecting the established speeds in the protocol, according to Table1.

Table 1: Characteristics of the tests circuit on the perimeter at the Interlagos Racetrack, with distance, track profile and speeds in km/h.

Section	*Distance (m)*	*Linearity*	*Departure*		*Arrival*	
			type	*speed*	*type*	*speed*
A	400	straight	downhill	20	uphill	35
B	400	straight	downhill	35	uphill	50
C	400	curved	downhill	50	uphill	20
D	400	straight	flat	60	flat	60

- this way, each test will be composed of 2 round trips on the circuit, with a total of 16 sections and a route 6.600m long.
- the bus used for the tests belongs to Viação Dutra, a Mercedes Benz model 1721, made on 2001, license plate CYB-8926, with Mr. Helio/Oscar as driver. The vehicle's preventive maintenance was up to date and no special preparation was made, except for the one necessary for the assembly of the Particulate Retainer.

3.3. Required Equipments for the Tests Procedures

According to Attachment 1, the tests protocol execution required the acquisition or manufacture of several specific components described below:

- rotary vane vacuum pump, manufactured by GAST, model 1023-101Q 60 Hz, with vacuum gage and needle valve.

- equalization chamber in galvanized steel, ϕ 230 mm x 400 mm (see attachment 4).
- insulated ϕ 3/4” hoses, Teflon lined, with threaded/quick release connections at the ends, manufactured by Inaflex.

4. Methodology

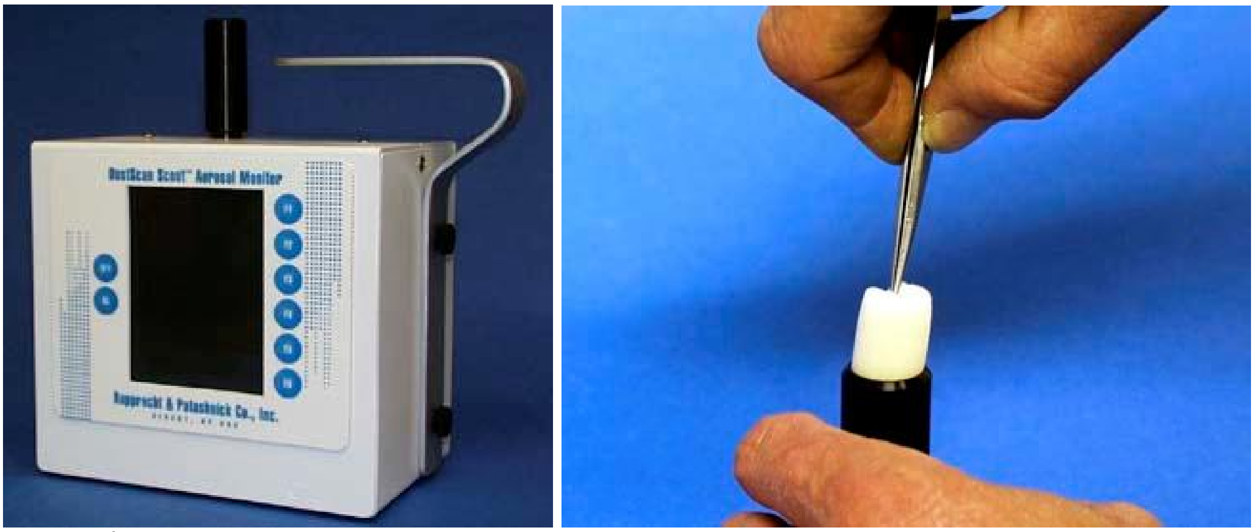
The tests procedure requires monitoring PM concentration, by instantaneous monitoring and material collection, besides training the driver to follow the established speeds.

4.1. Instantaneous monitoring of PM2.5

For instantaneous monitoring of fine PM concentration in the bus' discharge tube, a nephelometer, manufactured by Thermo/R&P, DustScan Scout 3020 Aerosol Monitor model with selector for PM2.5, was used (Thermo, 2006).

That device makes use of a light beam that goes through the flow of sampled air, and in the presence of suspended PM, there will be a light scattering allowing an instant reading of PM concentration to be obtained. That reading can be stored in internal memory, being a 2 seconds interval selected for consecutive storage of data. The collected data is, then, downloaded to a PC through specific software, generating, this way, a spreadsheet in the application MS-Excel, proper for statistical analysis.

Figure 1. Reproduction of the nephelometer DustScan Scout 3020 with PUF (polyurethane foam) selector for the admission of fine PM (until 2.5µm).



source: site www.rpco.com

The air inlet as well as the outlet were connected to the sample box with flexible hoses, equalizing the pressure inside the monitor.

4.2. PM2.5 Collector

The collection of PM will be done by gravimetric method, making use of a collector manufactured by Air Diagnostics with impactor for PM2.5 running at 10 lpm (Air Diagnostics, 2006), connected to a diaphragm vacuum pump manufactured by GAST model DOA101-P101-AA, using a flow control through a ϕ1/4" needle valve and flow indicator manufactured by Dwyer, model Mini-Master MMA-24.

The vacuum pump promotes the capture of an air flow at the sampling point, that goes trough the impactor for PM2.5, meaning that PM higher than 2,5 µm will be retained at this stage. The air flow with the inhalable PM, then, goes through a ϕ37 mm polycarbonate filter, capable of retaining the PM. The filters are weighed before and after the exposure, on a highly sensitive scale with temperature and humidity control, following specific protocol already validated. The collected deposited mass is obtained by the difference between weighs of the dirty and clean filter. The difference between the mass deposited on the filter for PM2.5 sampled before and after the Particulate Retainer, will make it possible to obtain an objective evidence of the device's PM capturing capability, called mass retained by the device.

4.3. Calculation of the average concentration of sampled air, or sampled concentration:

The calculation of the retained mass rate by the device per traveled kilometer is:

$$\text{sampled concentration} = \frac{\text{Mass retained by the device}}{0{,}6 * \text{sample duration}} \qquad \text{(equation 1)}$$

However, the amount this way calculated doesn't represent the real reduction of emission promoted by the device, due to the fact that the gas inflow in the exhaust pipe is not isokinetic, meaning, it is not proportional to the flow on the exhaust pipe.

4.4. Statistical Analysis

The data from the continuous PM2.5 monitoring in each one of the routes, as well as the 3 routes altogether that will characterize the test configuration, will be summarized by descriptive statistics, in the form of tables and graphs.

The group of routes from both configurations, with and without the device, will be analyzed and compared in order to verify if it is possible to identify, with adequate statistics significance, diferences between those configurations, using for this the Student t test (Bussab e Morettin, 2002).

The Minitab version 14 computer software will be used.

4.5. Preparatory activities

The driver must be submitted to a stage of adaptation to the circuit, simulating several times the route and compliance with the speed limits.

He also must be oriented in the sense of maintaining an uniform pattern of accelerating and slowing down throughout all the tests.

5. Results

Following what was established on the protocols and methodology, the stages of circuit and driver preparations were carried out days before the execution of the tests, which were done on July 3rd, 2006, from 10 AM to 3 PM, with good meteorological conditions, as per Table 2.

Table 2: Atmospheric conditions on July 1st, 2006 at the Interlagos Car Racetrack

Temperature (C)	*Relative Humidity (%)*	*Air Speed (m/s)*		*Atmospheric Condition*
		average	*maximum*	
16,3 ~ 24,9	33 ~ 69	0,4 ~ 0,6	1,1 ~ 2,1	sun

Both established configurations were tested: with and without the Particulate Retainer.

The continuous PM meter was adjusted to register one reading each 2 seconds. The scale was adjusted for up to 1 mg/m^3. The concentrations from the 6 routes in both configurations that composed the tests were registered. In the laboratory facilities, the recorded data was transferred from the PM monitor to an electronic spreadsheet and statistically analyzed. Table 3 presents the descriptive statistics of such data.

Table 3: Descriptive statistics of PM2.5 concentrations, considering each one of the configurations and routes, in mg/m^3

Configuration	*Route*	*N*	*Average*	*Medium*	*Standard Deviation*	*Minimum*	*Maximum*
without	#01	702	0,888	0,931	0,146	0,001	0,935
without	#02	677	0,876	0,932	0,158	0,001	0,935
without	#03	662	0,871	0,932	0,150	0,001	0,935
with	#01	662	0,708	0,916	0,275	0,000	0,934
with	#02	669	0,701	0,860	0,265	0,000	0,936
with	#03	671	0,719	0,868	0,264	0,001	0,933

N = number of valid measurements

As it can be seen in the above table, all the routes in the without Particulate Retainer configuration present medians very close to maximum, while in the with Particulate Retainer configuration, that difference is a little bigger. That way, it was decided to calculate the frequency of measures below 0,93 mg/m^3, by verifying the number of measures below that limit compared to total number of registered measurements. It was also calculated, for each route, the sum of the instant concentration and the total time spent for each route. The results are shown in table 4.

Table 4: Total number of measurements and measures below 0,93 mg/m^3 per route and per configuration, the percentage ratio between those numbers, the accumulated PM2.5 concentration and the duration of each test.

Configuration	*Route*	*N*	*N* (<0,93)*	*N*/N (%)*	*Accumulated Average*	*Duration (min:sec)*
without	#01	702	232	33	623	23:22
without	#02	677	201	30	593	22:34
without	#03	662	214	32	577	22:01
without	*all*	*2041*	*647*	*32*	*598*	-
with	#01	662	371	56	468	22:02
with	#02	669	485	72	468	22:16
with	#03	671	425	63	482	22:19
with	*all*	*2002*	*1281*	*64*	*473*	-

N = number of valid measurements; N* = number of measures smaller than 0,93 mg/m^3

It can be observed, in the above table that the percentage of measures below 0,93 mg/m^3 is, in average, 32% for the without Particulate Retainer configuration, while it is 64% for the with Particulate Retainer configuration.

The great concentration of values at the 0,93 mg/m^3 level puts in evidence that the adjustment of the PM monitor for the group up to 1 mg/m^3, may have been inferior to what was necessary, in other words, the numbers for the PM2.5 concentration found in the collected gas must exceed that amount.

It can also been seen that, in average, more than 68% of the measurements in the without Particulate Retainer configuration can be larger than 0,93 mg/m^3, while for the ones with Particulate Retainer configuration, only 36% may be bigger than 0,93 mg/m^3.

We present in Figure 2 the chronological series of measurements for each route.

Figure 2 makes the result obtained in table 4 even more evident, with a much larger amount of measurements at the superior limit of detection by the device for the “without Particulate Retainer” configuration than for the “with Particulate Retainer” configuration.

The collection of PM2.5, through gravimetric method, done at a constant flow of 10 lpm throughout the test in each configuration, resulted in 3 filters being taken to be weighed before and after the collection, leading to Table 5.

Figure 2: Chronological series of PM2.5 instant concentrations for each one of the performed routes in each test configuration

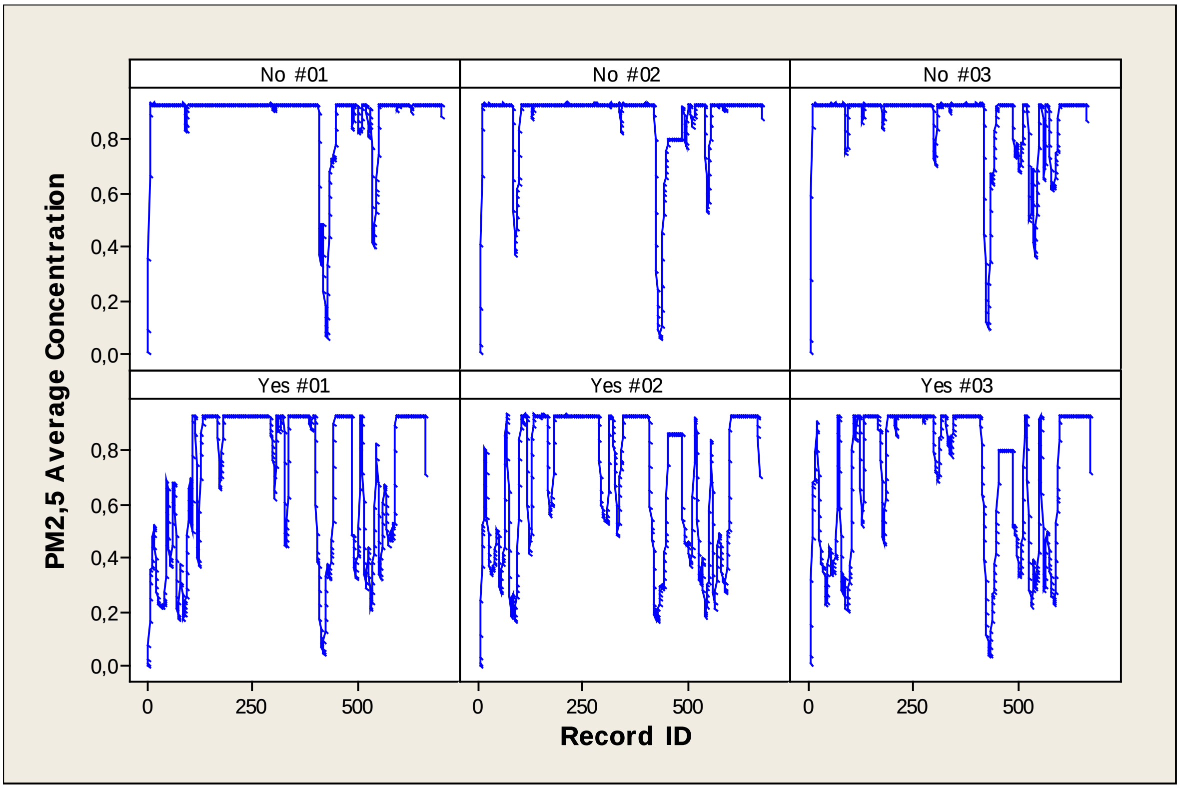


Table 5: Chronological series of PM2.5 instant concentrations for each one of the performed routes in each test configuration.

Configuration	*Position*	*Filter*	*Validation*	*Mass (mg)*
without Retainer	before	223	no	-
with Retainer	before	224	yes	1,640
with Retainer	after	226	yes	0,472

The filter used in the without Particulate Retainer configuration was not validated due to experimental error. Both filters of with Particulate Retainer configuration were validated. The difference of collected mass in both filters presents a value of 1,168 mg/m^3, in other words, the filter that was put after the Particulate Retainer presented a mass of 28% of the mass presented by the filter put before the Particulate Retainer.

The results above, considering the total sample period about 1 h 06 min 37 sec and with equation 1, the average concentration of the sampled air results:

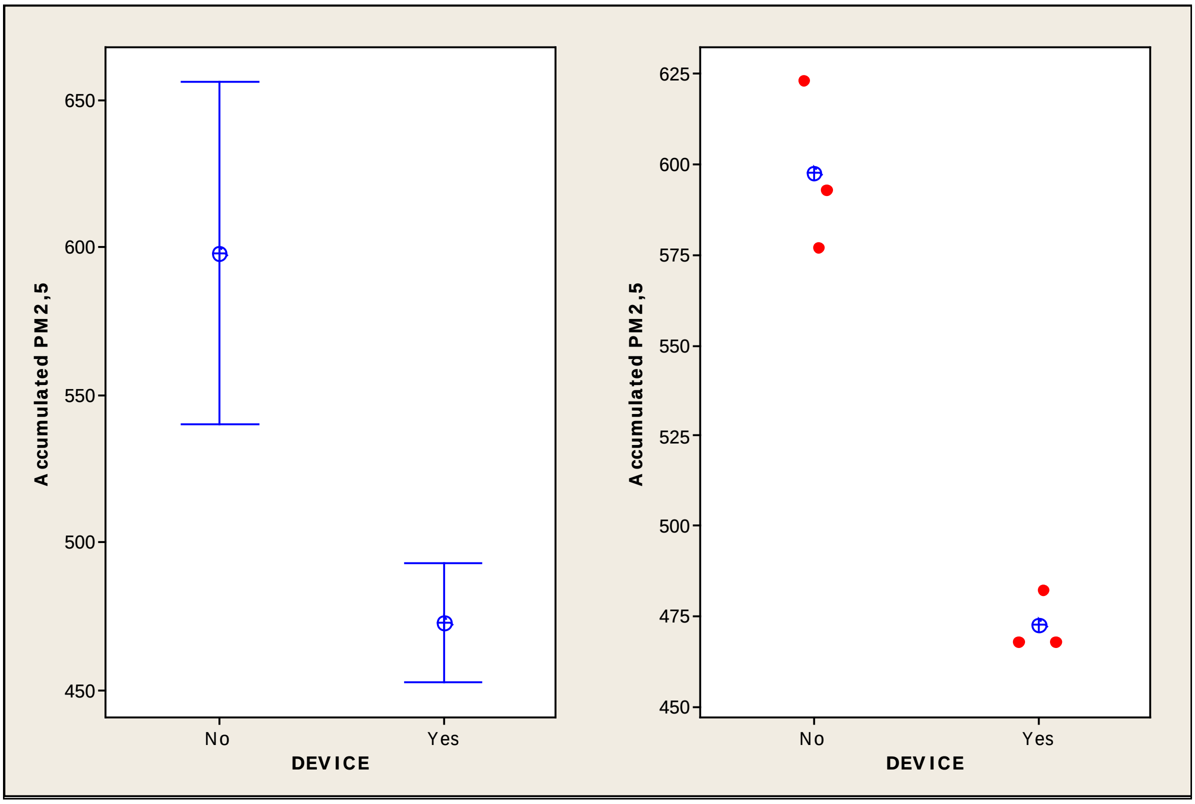
- sampled concentration before the equipment = 1.753 µg/m^3
- sampled concentration after the equipment = 709 µg/m^3

As it can be observed, the average concentration of sampled air collected after the Particulate Retainer has an order of magnitude inferior to the one before the equipment.

In order to verify if the test procedure is capable of detecting differences between the configurations, even considering that there was a "flattening" of the measurements of PM2.5 concentration bigger than 0,93 mg/m^3, we compared the averages of the routes in both configurations, resulting, by the criterion of defined analysis, in those averages being statistically different at the 1.3% level of significance.

In Figure 3 we have graphs that allow us to visualize that result more easily.

Figure 3: Individual values and averages of the accumulated concentrations and 95% confidence interval for the average of accumulated PM2.5 concentrations in each route per configuration



6. Discussion

Due to the fact that this approach has never been done before and to the several factors that were involved, the greatest challenge was to align the experiments of the many local agencies involved and interested in atmospheric pollution generated by vehicular emissions, in the making of this test protocol and in making it's execution viable.

The definitions adopted for the tests protocol, in terms of type of vehicle, circuit and care in order to guarantee that the test could be repeated and to obtain the same results, allow new tests to be done taking under consideration other configurations and/or equipments, and comparison among results.

It must also be recognized the need of implementations in the sense of adding more capacity and resolution to the protocol.

Despite being discussed, among the items that must be evaluated for the development of this protocol, these must be listed: instant measurement and registration of the rotation and required torque from the engine and fuel consumption; registration and evaluation of the fuel that was used; load weight during the test.

Among the items that need to be improved there are: topographic study of the circuit (distances and heights); system for speed registering and control; protocol for driver's training; continuous system for measuring and controlling atmospheric variables (wind speed, temperature and air humidity); communication system beneath driver and crew.

There was, also, an inadequate preparation for the adjustment of the PM2.5 monitor, what didn't allow the use of results in their plenitude. That fact will generate the inclusion of additional care when preparing the test, to the protocol.

The placement of PM2.5 collectors will also be object of repositioning, leaving them in vertical and not horizontal position, avoiding, this way, the possible loss of collected PM during the test due to the shaking of the vehicle.

Although the proposed protocol is not covered by any standard test international or by Brazilian environmental agencies, its structure reproduces situations of speed, distance between stops and the most used vehicle for transportation in the Metropolitan Region of Sao Paulo.

The first important matter in the tests protocol was to verify its capacity to point out the existence of behavioral differences when placing the equipment to be evaluated. Even considering the PM monitor set-up adjusting error, the accumulated PM2.5 concentration obtained in each route allowed 3 measurements for each test configuration to be obtained, and through those results the statistical test allows us to affirm, with a descriptive level of 1.3%, that a difference exists and can be identified, in other words, the protocol is sensitive enough to detect differences between the tested configurations.

The results of this present series of studies indicate that the average concentration of PM2.5 collected on the evaluated bus, was reduced from 1.753 $\mu g/m^3$, before the Particulate Retainer to 709 $\mu g/m^3$, after it, indicating a reduction of 60% in the average concentration of sampled air. Even considering that the collection of this protocol is not isokinetic, it is important to point out that both PM2.5 collectors operated in the same flow of capture, indicating that the difference in collection between them is due only to the Particulate Retainer.

7. Conclusions

Facing the proposed objectives for this study we can conclude that:

- Ø The protocol reproduces, the characteristics of the average speed and the most representative speeds, bus model, and distance between bus stops on the bus lane of the city of Sao Paulo;
- Ø The test was sensitive enough to identify differences between the use-no use of the Particulate Retainer when installed in a diesel bus, with a descriptive level of 1.3%;
- Ø The average concentration of the sampled air of PM2.5 after the Particulate Retainer was about 60% smaller than the one collected before the Particulate Retainer;
- Ø As the PM sample collection in the discharge tube is not isokinetic, it is not possible to compare the results from the present test with the ones obtained in tests with dynamometer. What can be deduced is that the equipment that was tested promoted significant reductions of emissions of PM2.5 in the experimental conditions of the present protocol;
- Ø In case the efficiency of the Particulate Retainer is confirmed by additional tests that will include measurements of fuel consumption and engine rotation (see suggestions list below), the manufacturer can feel safe to submit the device to a conventional protocol of evaluation with dynamometer. In our best understanding, this will be the shortest way to validate the Particulate Retainer and to adopt it as an instrument for controlling emissions from diesel vehicles, which, according to our studies, promote significant harm to the population's health in our city.

8. Suggestions

It becomes evident, through the obtained results, that it is necessary to continue to develop the present protocol, as described in the comments chapter, conducting more tests, including also the same configuration tested here.

Other actions can also be implemented in order to compose the scenario with the results obtained here, considering that there is already a garage that has the equipment installed in its buses. In this case, the implementation of a maintenance registry, when the Particulate Retainer is taken out for cleaning, proceeding to weigh the collected PM mass, its granulometric analysis, the amount of kilometers traveled and the total fuel (with origin) consumption since the last cleaning, can create a complementary indicator for validating the rate of PM retention provided by the Particulate Retainer, making possible to obtain other information of interest such as retained mass per liter of fuel and rate of retention per fraction of retained PM.

9. References

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Thermo Electron Corporation; DustScan Scout Model 3020 Aerosol Monitor; at http://www.rpco.com/products/ambprod/amb3020/index.htm accessed on August 28, 2006.

Air Diagnostics and Engineering Inc. Indoor Aerosol Monitoring Equipment; at http://www.airdiagnostics.com/indoor_samp_equip.html accessed on August 28, 2006.

ATTACHMENT 1

Experimental Procedures for Tests - Prj-603

Experimental Procedure for Tests – Prj-603

Application: Monitoring of emission of particulate matter generated by diesel mobile source.

Objective: To verify behavior of the particulate matter retention device installed in bus, in actual situation of usage.

Interested Party: Green and Environment Municipal Secretary's Office

Description:

The Particulate Retainer to be tested uses several associated technologies during the stages of filtration of discharged gas from the engine:

- bimetallic spiral;
- sleeved filter;
- electrostatic filter.

As the intention is to obtain indicative data about the emission of particulate matter in actual situation of usage, we are going to use a bus where the equipment to be tested is installed.

As plan of experiment, the intention is to use the same bus traveling trough a established route that simulates the usual situations of circulation (uphill, downhill, flats, etc.), but without variation to its internal load (passengers).

That vehicle will have the discharged gas collected, and the instant concentration of particulate matter in its fine fraction (PM2.5) will be measured continuously. Samples of fine particulate matter (2,5µm) will be collected by filters, before and after the Particulate Retainer, as a form of validating the continuous measurement process and to allow a future characterization of the collected material.

The same route will be traveled 3 times with the same configuration for Particulate Retainer. It will be considered the configurations of interest as follows:

- without the Particulate Retainer

• with all the stages of the Particulate Retainer

• with combinations of stages of the Particulate Retainer.

The values for the concentration of particulate matter measured in each one of the campaigns, with each Particulate Retainer configuration, will compose a spreadsheet suitable for the statistical processing.

Descriptive statistic of each configuration and campaign will be done in the form of tables and figures for the characterization of the obtained experimental values.

It will also be verified the existence of statistically significant difference in the reduction of the collected samples among the several configurations of the Particulate Retainer, which results will be expressed in terms of tables, equations or figures, for better visualization and comprehension of the results.

Cycle

In order to establish a route and gear situations that would represent, during the test, the local use, it is intended to obtain some information from the transportation management public offices, including:

• speed of operation: average, maximum and minimum;

• average distance between bus stops;

• average time spent at the stop;

• transported load: average, maximum and minimum.

Based on this information a characteristic route will be defined, generating a spreadsheet of attendance that will be followed in all the campaigns. It will also be selected a site that will facilitate the implementation of this route inside a 30 minutes period (maximum) approximately.

The execution of this protocol must also avoid sources of variations that can interfere with the study. It is recommended to maintain during the simulations the following:

• same driver;

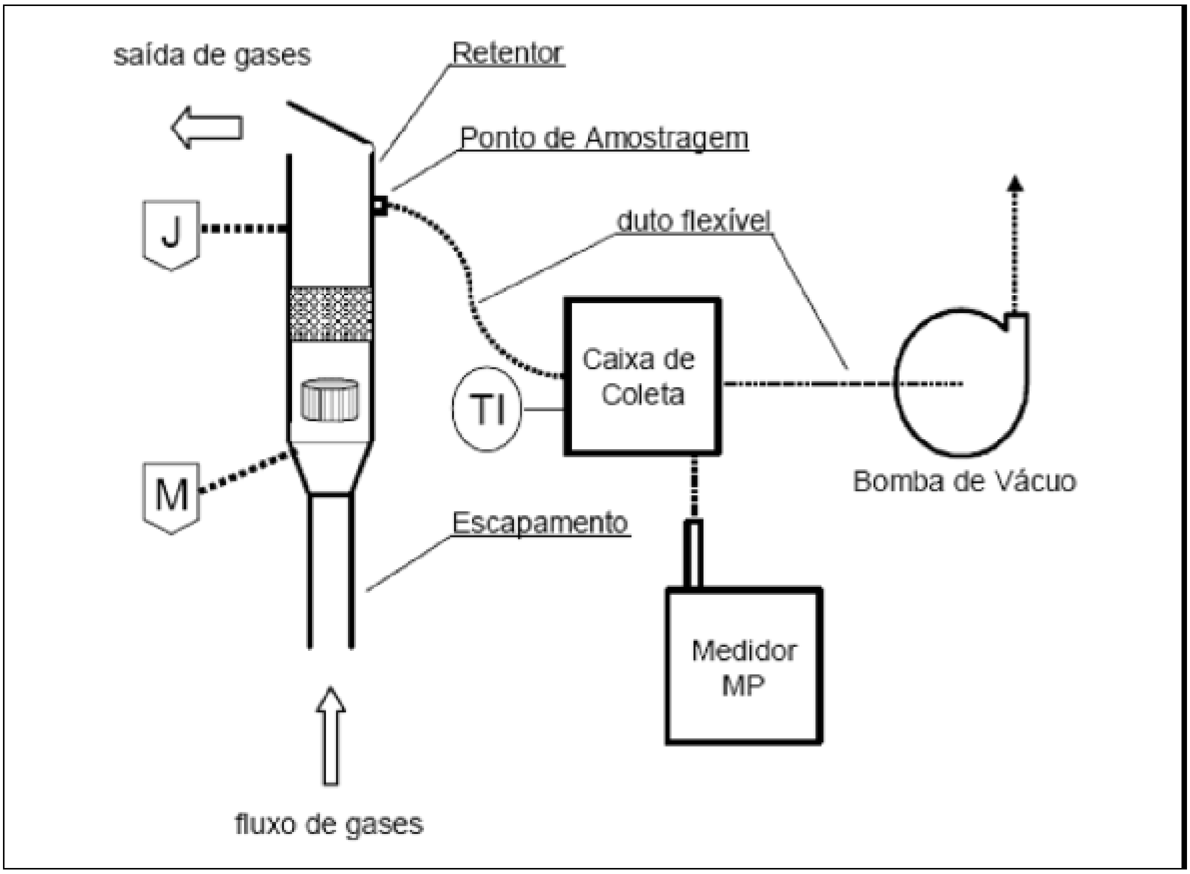
• same load of ballast, if previously adopted and defined;

• same hours and not in significantly different climatic conditions.

Conception of Construction

For the execution of the monitoring, the installation, detailed in Figure 1, will be done, where the various components are identified.

Figure 1: Diagram of the particulate matter test installation in order to allow the collection of gas exhaustion from diesel engine at the exit of the Particulate Retainer.



Sampling Point (“*Ponto de Amostragem”*): On the Particulate Retainer’s body, after the 3 devices (J) and before the atmospheric discharge of gas produced by the engine, it will be installed a sampling point of that gas which will be a connection perpendicular to the Particulate Retainer’s wall, suitable for connecting a flexible hose to.

Collection Box (*“Caixa de Coleta”*) Between the sampling point and the vacuum pump, a collection box will be installed allowing the availability of enough volume of gas for the extraction to the particulate matter meter, besides being able to fade any possible pressure pulse.

PM Meter (*“Medidor MP”*) The particulate matter monitor, using light scattering principle to “measure” the particle air concentration, is ready to retain particles with an aerodynamic diameter greater them 2.5μm, guaranteeing the measurement of only the fine fraction particles, capable of penetrating the human respiratory system.

That monitor works in continuous mode and has a memory suitable for the automatic registering of measurements done, with identification of date, time and monitored campaign, allowing transfer of stored information to electronic processing afterwards.

Vacuum Pump: In order to avoid that the engine rotation interferes in the collection, a vacuum pump will be installed, a positive displacement type, to guarantee, with the collection box, an approximately constant extraction flow.

PM Collection: Simultaneous collections of PM in the inhalable fraction (aerodynamic diameter 2.5μm) will be done at two stages during each campaign: one in the Particulate Retainer inlet, and a second one, on the Particulate Retainer outlet. Those collections will be used to verify, gravimetrically, if there was an objective reduction of emission, and to validate the continuous monitoring system being used. In the future the filters can be submitted to instrumental analysis to characterize the collected material.

Products

At the end of the experiment and the analysis of generated data, it will be produced a complete report on the protocol, detailing and justifying the methodology, describing the experiment, and presenting the generated data, the developed data analysis and obtained results, including chapter with conclusions and comments.

This report will be developed in two versions:

- complete, destined to the technical public used to scientific experiments, containing all the references, data, analysis and considerations that support the document.
- summarized, destined to the public that make the decisions, who need to have a more summarized, accessible and suitable text for their own use.

Suppositions and Restrictions

This protocol has as main objective to perform a relative evaluation of the particulate matter concentration behavior in the gas discharge of a diesel vehicle's exhaust pipe, taking under consideration different components configurations that look to reduce particulate matter before its discharge in the environment. It doesn't allow to quantify the mass of particulate matter that will be released in the atmosphere, among other reasons, because it doesn't measure, direct or indirectly, the gas flow in the discharge tube.

The protocol doesn't answer to the requirements nor substitute the standard tests prescribed for measuring the emission from the engine defined and accepted by the legislation in use. That is why the results must be used on the level of a relative evaluation.

Recommendation

It will be verified the possibility of registering the regime of engine rotation, being the composition of that information allowed with the monitored PM concentration, to estimate the total emission during the circuit.

LPAE

The LPAE – Laboratory of Experimental Air Pollution belongs to the Pathology Department at the USP Medical School, being the oldest and most highly regarded group in atmospheric pollution and health research.

It is led by Ph.D. Paulo Hilário Saldiva, pathologist doctor, and head of the Pathology Department at the FMUSP, I-A level researcher of the CNPq, and participant in the panel of researchers who are elaborating the new standards of air quality to be recommended by the World Health Organization.

ATTACHMENT 2
Bus Lane Analysis – Tests Protocol

Objective

To perform an analysis of the data collected by Voith, in vehicle equipped with automatic transmission and data monitoring system.

To use the analyzed data for proposing a protocol for testing the emission through the Particulate Retainer already programmed.

Data Source

It was received an electronic spreadsheet on Excel, with data referred to "Largo Sao Francisco – Varginha Terminal" bus route lane (Mercedes Benz vehicle – articulated), collected in May, 2006 (no register of day), starting at 12:00 PM, considering the following fields:

§ time spent in hour, minute and seconds (with thousandths)

§ instant speed, in km/h

Methods

In order to analyze that database, several fields were created with the intention of better characterize it, in terms of cycles of operation, considering successive stops, time, speed and distances.

The analysis done intends only to obtain a description and summary of the main characteristics of that data.

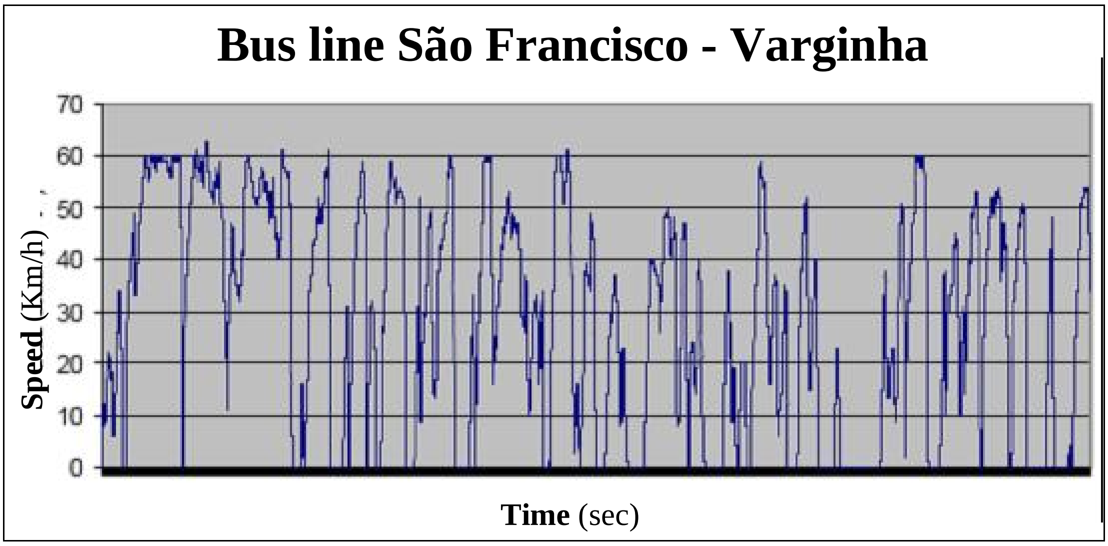
Results

The main received database characteristics are indicated in Table 1.

Table 1: Summarized data from the complete database, as it was received:

Characteristic	value	scale	notes
Total time	1:06:14	h:min:sec	until final stop
Minimum interval	0.020	second	between records
Maximum interval	4.944	second	between records
Minimum speed	0	km/h	
Maximum speed	64	km/h	

Figure 1: Speed along the time spent on the route.



From that database, the following variables were calculated:

- time spent between each on the database record
- distance traveled during each time spent
- speed cycles considering the consecutive period between points of zero speed
- speed cycles considering, additionally, that the minimum distance between immobility varies from 10 to 100m, with increments each 10m
- cycles characteristics such as time, distance and maximum speed.

This being, we present the obtained results on tables 2 to 5.

Table 2: Frequencies of speeds and percentage over the total time spent in the circuit and percentage over time in movement.

Speed		Percentage of time	
from	to	with stops	without stops
0	0	21,87	
1	9	4,24	5,43
6	10	4,60	5,89
11	15	4,95	6,33
16	20	5,60	7,16
21	25	5,07	6,49
26	30	6,64	8,49
31	35	6,96	8,91
36	40	6,17	7,90
41	45	6,15	7,87
46	50	7,38	9,44
51	55	7,48	9,57
56	60	12,09	15,47
61	64	0,81	1,04

Table 3: Number of cycles during the circuit, considering that stops cannot occur on distance inferior to 0m, up to 100m

Minimum distance (m)	0	10-20	30-60	70	80	90	100
Frequency (times)	45	40	39	38	37	35	34

Table 4: Total distance (meters), maximum speed (km/h) and duration (sec), for each cycle considering stops above 60 m and 100 m

Paradas acima de 60 m				Paradas acima de 100 m			
ciclo	distancia	Velocidade máx	tempo	ciclo	distancia	Velocidade máx	tempo
1	276	34	79	1	276	34	79
2	2374	60	174	2	2374	60	174
3	4435	63	361	3	4435	63	361
4	884	61	79	4	976	61	125
5	91	31	46	5	463	59	47
6	463	59	47	6	139	32	27
7	139	32	27	7	850	59	92
8	850	59	92	8	1384	60	220
9	1300	60	200	9	1938	60	210
10	84	33	20	10	943	61	88
11	1938	60	210	11	385	49	48
12	943	61	88	12	381	37	135
13	385	49	48	13	1168	50	125
14	381	37	135	14	263	40	52
15	1168	50	125	15	303	38	148
16	263	40	52	16	897	59	105
17	231	38	109	17	574	52	248
18	72	20	40	18	1282	60	165
19	897	59	105	19	923	53	110
20	485	52	83	20	867	54	80
21	89	23	165	21	429	51	54
22	1282	60	165	22	211	48	128
23	923	53	110	23	1330	62	128
24	867	54	80	24	259	37	40
25	429	51	54	25	406	45	86
26	211	48	128	26	242	29	129
27	1330	62	128	27	1229	60	157
28	259	37	40	28	673	53	71
29	406	45	86	29	903	61	110
30	164	29	82	30	934	60	75
31	78	20	47	31	2173	64	191
32	1229	60	157	32	308	50	59
33	673	53	71	33	232	34	62
34	903	61	110	34	171	30	42
35	934	60	75				
36	2173	64	191				
37	308	50	59				
38	232	34	62				
39	171	30	42				

Table 5: Descriptive statistic for cycles with stops above 60m and 100m.

	N	Average	Median	Minimum	Maximum
Cycles above 60 m					
Distance (m)	39	777	463	72	4435
Time (min:sec)	39	1:42	1:23	0:20	6:01
Máximum speed (km/h)	39	47	51	20	64
Cycles above 100 m					
Distance (m)	34	892	761	139	4435
Time (min:sec)	34	1:57	1:47	0:27	6:01
Máximum speed (km/h)	34	51	53	29	64

Tests Protocol

Based on the above results, it is intended to propose a protocol for the execution of tests of emissions in bus. For that matter, it is important to list some of the basic premises that should be attended:

1. Reproducibility: it is recommended that the protocol be able to be reproduced at any time, allowing the comparison among results from different campaigns. This exigency, in physical terms, presupposes:

§ physical use of a same space for executing the tests.

§ establishment of route, distance between stops, time of permanence and loaded weigh, that will configure a protocol capable of being reproduced.

2. Identification and definition of parameters of interest that will configure the urban situation in Sao Paulo.

§ distance between stops: 300 m to 500 m.

§ average speed: around 20 km/h.

This way, we propose, for this protocol, the following arrangements:

§ place: peripheral road and old opposite stretch at Interlagos Car Racetrack/SP, with an extension of 2 km approximately (circuit measurement still to be made), that has sections with slopes and few turns;

§ circuit: the complete lap should have from 7 to 8 sections, as follows:

  - § 2 to 3 sections that correspond to the necessary distance for the turns to be done with safety;
  - § 5 sections with length between 400 m and 500 m, where it will be possible to travel at speeds up to 60 km/h.

- § the execution of 4 complete laps in the circuit, completing a total test time between 20 to 30 minutes, counter clockwise.
- § reached speeds equivalent to the quartiles of speed obtained in the analysis of the actual aisle situation.

	#1	#2	#3	#4
Speed (km/h)	20	35	50	60

- § distribution of time at stops between each one of the 7 to 8 sections, in order to maintain the average speed of 20 km/h;
- § speed of 5km/h on the curved sections, for safety reasons.

This way, the four defined speed limits will be adopted on each one of the 5 sections, completing all the charge and slopes situations.

Preparatory Activities

Due to this be the first time this protocol is executed, it is necessary to have some stages of preparation carried out:

- § circuit perimeter measurement;
- § marking of each section on that perimeter, from the turns, with the places for stopping, allowing the placement of the necessary vertical signs;
- § several drives with the bus to be tested in order to determine, in each section, the distances of acceleration and slowing down;
- § determination of time spent at the stops between each section;
- § determination of the loaded cargo that will represent an average condition of the expected occupation inside the vehicle (to consider, besides the driver, at

least 3 more people for the control of monitoring procedures of instruments and driver supervision/help).

Complementary Notes

During the first execution of this protocol, other precautions, that can collaborate with the tests control and reproducibility, must be verified, such as: driver influence, fuel characteristics, environmental characteristics such as temperature, humidity and atmospheric pressure, among others.

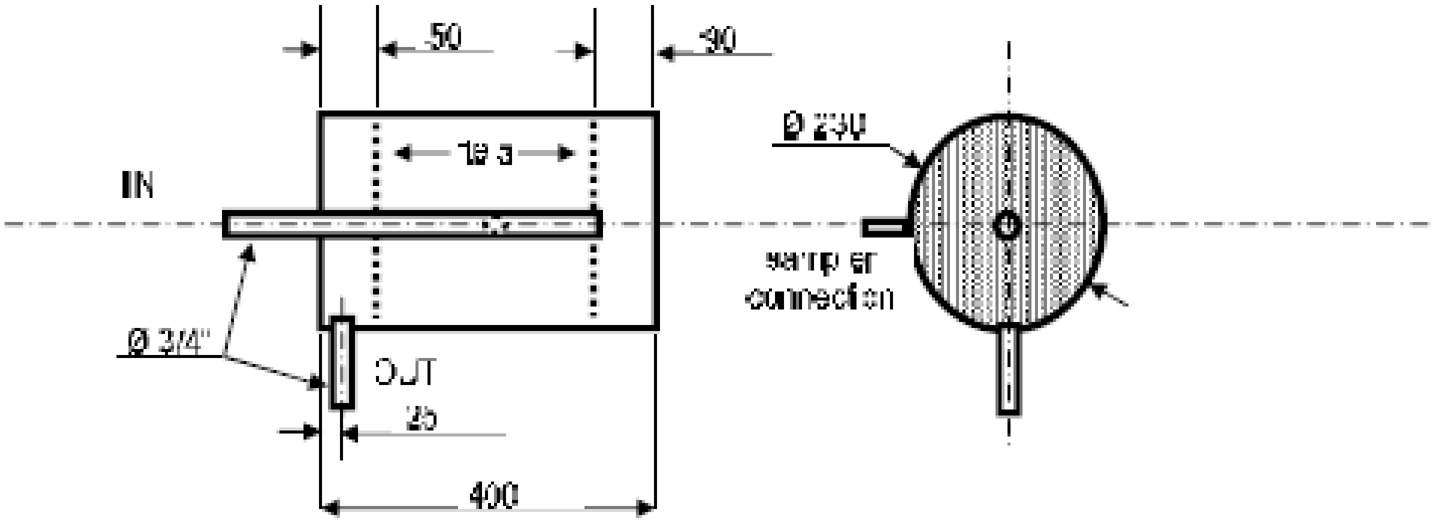
This protocol version needs to be approved by the participants. Even so, it has provisory character due to the inexistence of previous experiments, and consequent need of implementations and development.

ATTACHMENT 3
Air view of the test circuit at the Interlagos Car Racetrack


A
B
C
D
Test rout
Bus stop
Image © 2006 DigitalGlobe
© 2006 Europa Technologies
Google
Pointer 23°42'03.99" S 46°41'50.14" W elev 2492 ft
Streaming |||||||||| 100%
Eye alt 7212 ft

ATTACHMENT 4
Equalization Chamber

LPAE/FMUSP ***CÂMARA DE EQUALIZAÇÃO*** **ESTAPLAN**



IN = OUT = 3/4" rosca NPT (macho)
samper connection = 19 mm (external)

Dimensionamento dispositivo/Dimensional 1 listagem de 23/3/2006