COMPARATIVE STUDY OF THE EMISSIONS LEVELS/PASSENGER RATES BETWEEN HEAVY-DUTY AND LIGHT-DUTY VEHICLES IN URBAN TRAFFIC

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Abstract. *The emissions level of heavy-duty and light-duty passenger vehicles were studied in the same route in Porto Alegre - RS - Brazil. The main objective of this study was to find out the degree of emissions levels per passenger in light-duty vehicles in relation to heavy-duty vehicles. The results showed the advantage to use collective means of transport and the importance of projects which stimulate it in great urban centers, which have very poor air quality due to exhaust emissions of vehicles of the transport system This evaluation showed, in the worse comparisons, which the emissions levels/passenger rates had been increased of up 0,6 kg in terms of CO, more than 10.000% in terms of HC e 1500% in terms of NOx for light-duty vehicles in relation to heavy-duty vehicles at same route. In the best comparisons these increase also had been exaggerated: around of 0,2 kg in terms of CO, 2500% in terms of HC and 330% in terms of NOx.*

Keywords*: emission index, combustion, equivalence rate, means of transport, air quality.*

1. Introduction

In the late 1990s, following the example of other metropolitan regions, in the city of Porto Alegre - RS - Brazil, a set studies were developed aiming at obtaining the numerical model of the atmospheric air composition of Porto Alegre Metropolitan Region (PAMR). In this process, with the support of the Laboratory for Engines of Alberto Pasqualine Refinery - Petrobras and Laboratory for Engines of Universidade Federal do Rio Grande do Sul, Vilanova (1998) developed a technique to sample and carry out an exhaust gases analysis to determine the emissions index, in order to inventory the PAMR vehicle fleet exhaust emissions. This procedure allowed us to study and assess emissions differences in typical vehicles running on equal routes. In this comparative evaluation, it was possible to demonstrate the increased emissions levels/passenger rate of light-duty vehicles in relation to heavy-duty vehicles. This difference is due to the capacity of the latter to transport a bigger amount of passengers than the former, differences in motorization and fuel requirements.

Demonstrations of this nature are useful to justify projects and actions which aim at encouraging transportation with heavy-duty vehicles in great urban centers, as a means to decrease pollutant emissions index in these regions, thus contributing towards an improved atmospheric air quality.

2. Materials and Methods

2.1. Materials

2.1.1. Vehicles used in the study

Initiating with the heavy-duty vehicles fleet, used as collective means of transport, some significant vehicles were chosen for the sample. Different configurations were selected, with different ages and good conservation conditions, which is common in the PAMR vehicle fleet.

Three vehicles were selected in terms of age: a vehicle with high mileage accumulation, a vehicle with half mileage accumulation and a new vehicle with low mileage accumulation, two configurations Mercedes Benz, one naturally aspired and the other supercharged, and a supercharged MWM, which equip Volkswagen vehicles, which were the most modern ones found in the fleet at that time. As a light-duty vehicle, an automobile VW, Gol CL model was chosen. Table 1 shows with details the characteristics of the vehicles sample selected for this study.

2.1.2. Fuels

Typical diesel oil with low sulphur content was used in heavy-duty vehicles in this study. It is known as "Metropolitan Diesel Oil" and it is distributed in PAMR with the objective of lowering the SO_x emissions. On the other hand, fuel mixtures with gasoline and 22% anhydrous ethanol (gasool), and gasoline with 15% MTBE, had been used as combustible in light-duty vehicles. The latter has been used in all Southern Brazil as an alternative to the ethanol lack in Brazil in the late 90s. The first mixture has normally been used in the rest of the country.

Table 1 – Characteristics of the vehicles sample.

Motorization	**Accumulate mileage** (km)	**Age** (years)	**Fleet participation** (%)	**Vehicle**
MB OM 366 naturally aspired	100.000	6	38	Heavy-Duty
MB OM 366-A supercharged	100.000	4	45	Heavy-Duty
MWM 6.10T supercharged	50.000	0,33	< 9	Heavy-Duty
WV AP 1.8 naturally aspired	100.000	6	-	Light-Duty

2.1.3. System of sampling of the gases

The system of sampling of the gases was developed by Vilanova (1998), and will be only briefly described in this text. It consists of a suction pipe located at exhaust pipe and hardwired in a vacuum pump. Its discharge is made in a sampling balloon previously voided and installed in the vehicle. To the end of the route all gas contained in the balloon proceeds only from combustion and its composition represents the emissions in the urban way. The system above is presented in Fig. 1.

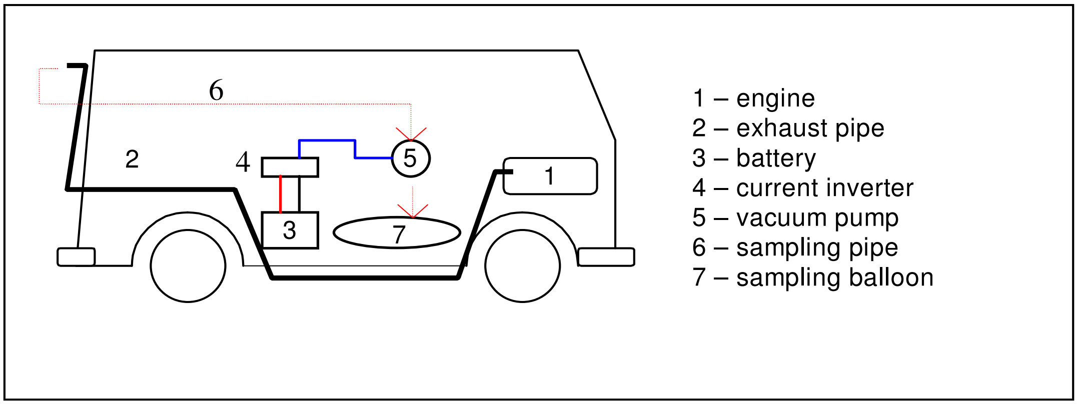

Figure 1. System of sampling of the gases developed by Vilanova (1998).

2.2. Methods

The methodology is fully described in Vilanova (1998). For the choice of the urban ways used in this study, the collective transport routes of the city were considered. The distance covered by the vehicles and the kilometer passengers index (IPK) were also taken into consideration, using the averages of these parameters for the urban ways as a criterion.

The gases were sampled for all routes, and they are stored in a sampling balloon. Then, analyses in terms of O_2, CO, CO_2, NO_x and HC were carried out immediately to the ending of the route, in a gases analyzer installed at the terminal, with non dispersive infrared method (NDIR). From fuel consumption and composition, as well as from analysis of the exhaust gases, it is possible to infer the emissions index per kilometer. The measure of IPK in the route easily determines the emissions levels/passenger rate in grams.

The routes were covered at two different schedules; the choice was made in accordance with the traffic conditions, always considering both a schedule with good traffic conditions and another one either with bad traffic conditions or very slow traffic. In order to define this criterion, the time which was necessary for the vehicle to cover the route was used, presuming that a short time indicates good traffic conditions whereas a long time indicates bad traffic conditions.

3. Results

Table 3 presents the emissions levels/passenger rate measured per vehicle and in each tested route. The emissions had been determined in grams of pollutants per passenger, during T2 Bus route of Carris Portoalegrense Company, with south terminal at *Praia de Belas Shopping* station, and north terminal at States Avenue, Airport station.

Table 2. Tests codes in accordance with the vehicle and the fuel.

Vehicle/Engine/Fuel	**Tests codes**
VW Gol CL/AP 1.8/gasoline+22% anhydrous ethanol	22AEAC
VW Gol CL/AP 1.8/gasoline+15%MTBE	15MTBE
Mercedes Benz/ OM 366-A/Diesel	OM 366-A
VW/6.10 T/Diesel	VW 6.10T
Mercedes Benz/ OM 366-A/Diesel	OM 366

Table 3. Levels/passenger rate measured in T2 Route - 38 km.

Test	**Traffic Conditions**	**IPK**	**CO**		**HC**		**NO_x**	
		passenger/km	g/km	g/passenger	g/km	g/passenger	g/km	g/passenger
15MTBE	Bad	0,05	34,4	626	0,0541	0,9851	0,2	4,4
15MTBE	Good	0,05	26,1	475	0,0502	0,9137	0,3	5,0
22AEAC	Bad	0,05	18,0	329	0,0470	0,8602	0,3	6,1
22AEAC	Good	0,05	11,8	215	0,0338	0,6160	0,3	5,1
OM 366	Bad	8,35	13,2	2	0,1228	0,0147	5,4	0,6
OM 366	Good	4,03	10,0	2	0,0962	0,0239	6,0	1,5
OM 366-A	Bad	8,00	8,4	1	0,0645	0,0081	3,2	0,4
OM 366-A	Good	4,79	6,9	1	0,0594	0,0124	4,3	0,9
VW 6.10T	Bad	5,46	0	0	0,0722	0,0132	2,4	0,4
VW 6.10T	Good	3,76	0	0	0,0530	0,0141	2,7	0,7

Figure 2, Fig. 3 e Fig. 4 present the comparative emission levels/passenger rate per vehicle selected and pollutant. The left columns show the measures of emissions of the light-duty vehicle evaluated with two fuel mixtures: gasoline + 15% MTBE and gasoline + 22% anhydrous ethanol. The three last pairs of columns present the measures of emissions of the heavy-duty vehicles evaluated. The left column of each sequence presents the emissions of the vehicles in good traffic conditions and the column to the right represents the emissions with bad traffic conditions.

Figure 5 presents the NO_x emissions index measures per vehicle in grams per kilometer in both good and bad traffic conditions.

4. Discussion

In accordance with Heywood (1988), the carbon monoxide (CO) emissions levels are mainly related to the air/fuel equivalence rate. The author explains:

> *"When the data are plotted against the relative air/fuel ratio or the equivalence rate, they are correlated by a single curve. For fuel rich mixtures CO concentrations in exhaust increase steadily with increasing equivalence ratio, as the amount of excess fuel increases. For fuel-lean mixtures, CO concentrations in the exhaust vary little with equivalence ratio and are of order* 10^{-3} *mole fraction."*

The figure described by the author is widely known, and can also be found in Taylor (1976), Vilanova (1998), Guibet (1997) amongst a number of references. It shows a significant increase of CO emissions index in engines which operate with rich mixture. This can be easily explained, as lack of oxygen in this condition prevents the complete oxidation of carbon in CO_2.

Light-duty vehicles, which normally use spark ignition engines (Otto cycle), operate in with an equivalence rate varying between rich and stoichiometric, thus emitting a considerable amount of CO. On the other hand, the heavy-duty vehicles which use compression ignition engines (Diesel cycle) and operate with air excess have very reduced CO emissions index. As the amount of passengers in the same route is greater in heavy-duty vehicles, the disadvantage of systems of transport with light-duty vehicles becomes apparent, as one can see in Figure 2. The light-duty vehicles (22AEAC) emitted up to in absolute terms between 215g to 475g more CO in good traffic conditions than heavy-duty vehicles (VW 6.10T) and between 329g to 626 g more in bad traffic conditions.

In relation to unburned hydrocarbons emissions, several factors affect the degree of those emissions. The main ones are: air/fuel equivalence rate, age of the engine, temperature of work, and point of distillation of the fuel. However, the greatest influence on the increase of unburned hydrocarbons is the incomplete combustion. Figure 3 shows the increase of emissions of HC's in bad traffic conditions, mainly to light-duty. In those traffic conditions, repeated speed changes and load conditions changes are necessary because of excessive stops and speed reduction, which increases both the incomplete combustion in this transient engine operation and the emissions of HC's.

Although both types of vehicles presented sensitivity to traffic conditions changes, Figure 3 shows the disadvantage of using light-duty vehicles for passenger's transportation and the increase of damages caused by its use in relation to HC emissions.

The type of fuel must also be considered in this criterion, that is, the difference of point of distillation of diesel for gasoline mixtures. However, the change of this characteristic on the HC emissions was not evident by changing 15MTBE to 22AEAC.

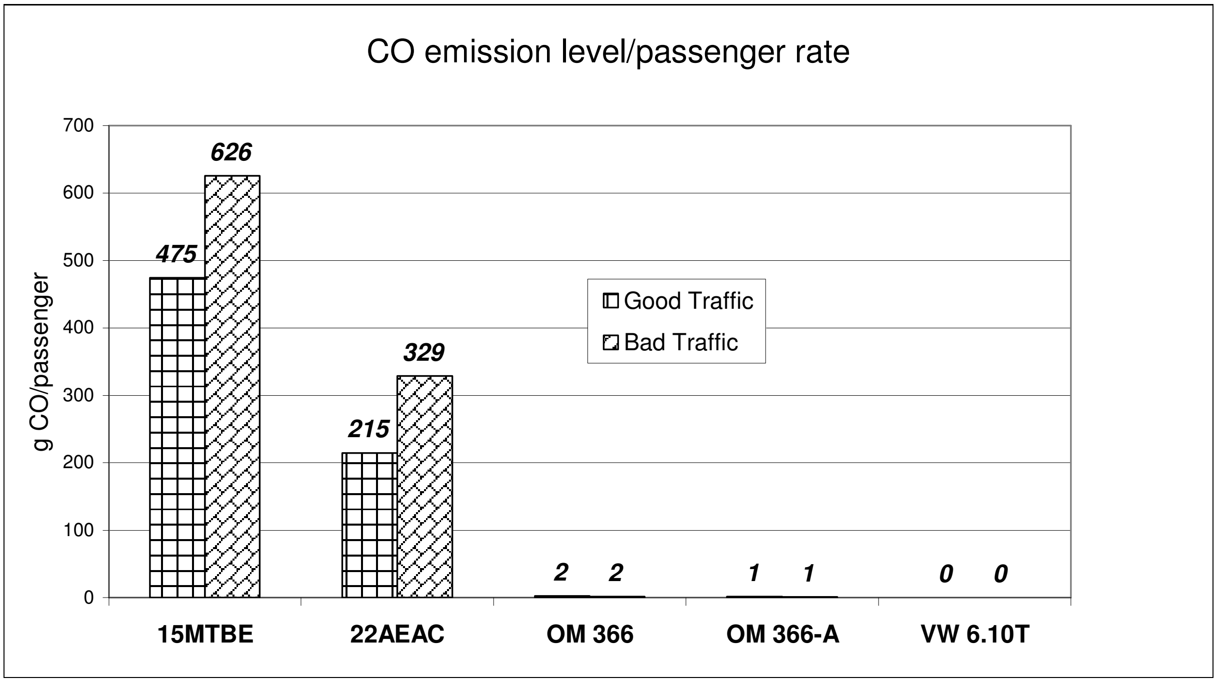

Figure 2 – Comparative CO emission levels/passenger rate per vehicle.

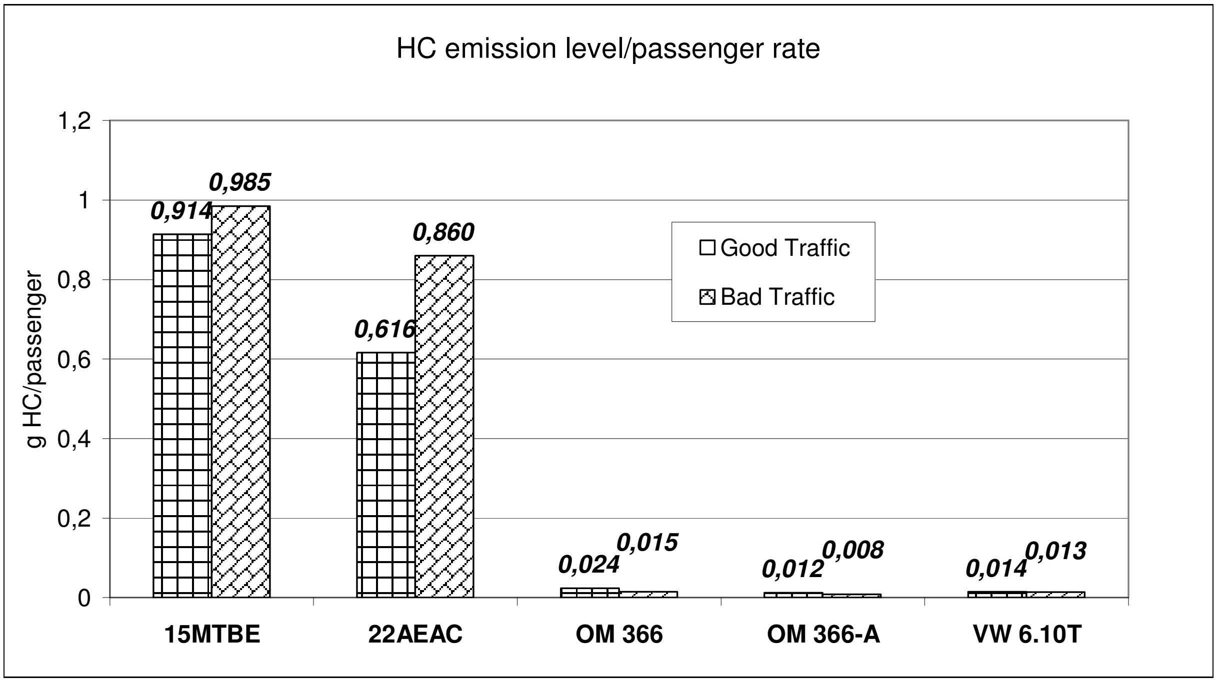

Figure 3 – Comparative HC emission levels/passenger rate per vehicle.

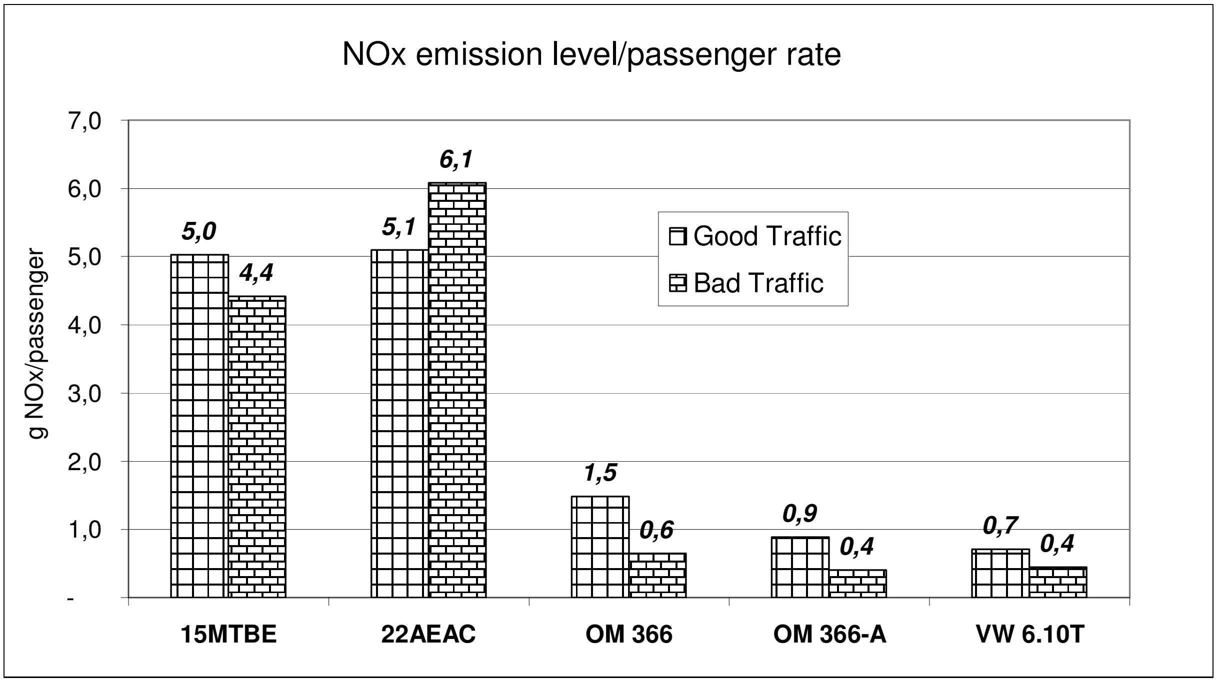

Figure 4 – Comparative HC emission levels/passenger rate per vehicle.

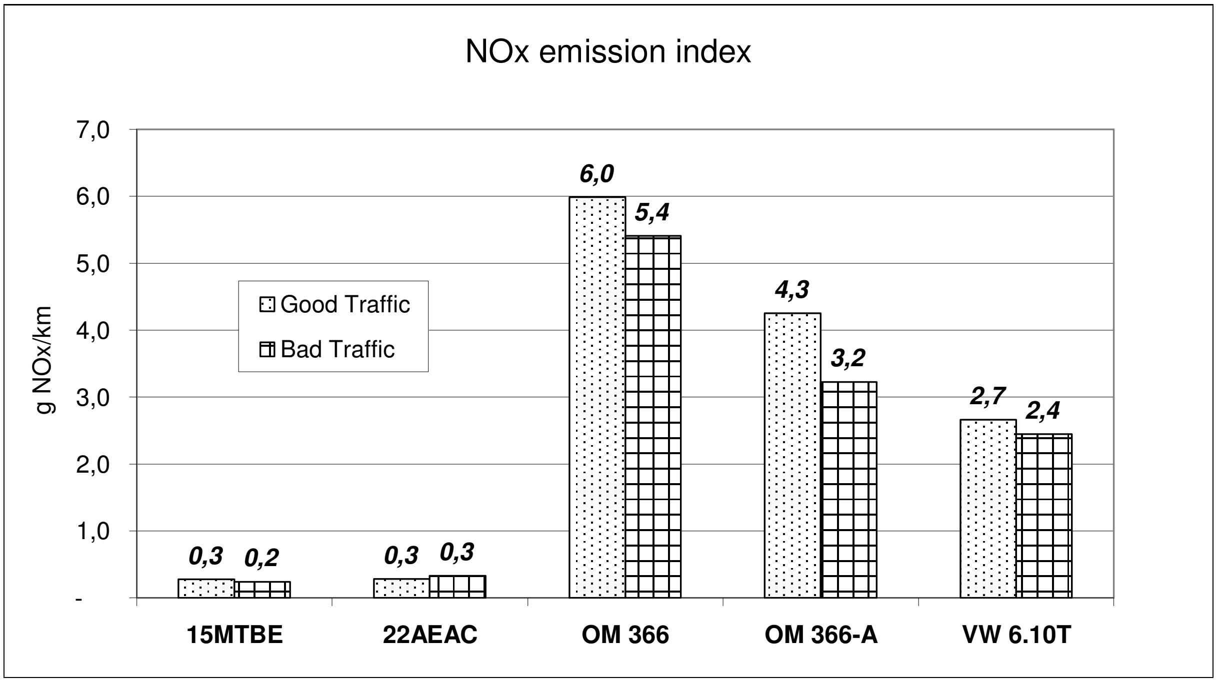

Figure 5 – Comparative NO_x emission index per traffic conditions.

The nitrogen oxides (NO_x) formation is directly related to the oxidation of nitrogen of air when it is submitted to high pressures and temperatures. Therefore, how many bigger pressure and temperature in the combustion chamber are, bigger the NO_x emissions will be.

The presence of these pollutants in atmospheric air has caused a great concern due to its intense activity in the atmosphere, producing intermediate composites which are harmful to human health as well as to the atmosphere.

A big number of works and actions have been undertaken and developed to reduce these emissions in the urban centers. Heavy-duty vehicles, which operate in the transport system, have been considered as the main emission sources. As those vehicles operate with Diesel engines, they produce a great amount of NO_x because of the conditions in which the combustion occurs: with excess of air and high pressures.

In light-duty vehicles and Otto engines which operate with lower pressures and temperatures, emissions are lower than in heavy-duty vehicles. However, emissions of those pollutants can still be verified. Actions such as advance ignition optimization and recycling exhaust gases have been taken so as to reduce them.

Figure 5 shows NO_x emissions from both light and heavy-duty vehicles in grams for kilometer. Analyses as this have been presented to show the greater disadvantage of Diesel engines in relation to Otto engines, concerning NO_x emissions. In Fig. 5, two facts are evident. The first one is the reduction of NO_x emissions in bad traffic conditions. This is due to the fact that the combustion is more inefficient in this transient operation and the pressure and temperature are lower in this condition. The second one is the increased NO_x emission in mass per kilometer of heavy-duty vehicles.

However, in Fig. 4, we can see that, if we consider the emissions level/passenger rate in the route, heavy-duty vehicles present a great advantage in relation to light-duty vehicles. Even though light-duty vehicles cause fewer emissions mass than heavy-duty ones, is possible to state that a transport matrix on the basis of light-duty mainly, would cause an accentuated increase in global emissions, therefore a great number of them would be necessary to replace only one heavy-duty vehicle for the same amount of the transported passengers.

4. Conclusion

As we intended to demonstrate from the analysis of the data presented, it has become evident that there is an advantage in using collective systems of means of transport to the detriment of the private means of transport in basis of the emissions levels/passenger rate. It is very evident in evaluation of NO_x emissions, where actually the restriction actions are concentrated on the collective transport, the advantage of this type of transport becomes very clear when it is evaluated in terms of the emissions levels/passenger rates and not for NOx emission index. In terms of the CO and HC, the differences between emissions' index of the heavy-duty and light-duty don't are much accented, but they have been significant when are showed in terms of emissions levels/passenger rate. Although, actions which encourage the use of collective transports in urban centers with vehicles' high concentrations are important for to reduce the pollutant emissions of this vehicles.

An important fact in this study is that the emissions were not estimated. They were measured in vehicles which were effectively used in standard routes of an urban area.

As it was expected, the results also show the sensitivity with which the vehicles respond to its emissions in relation to the alteration of traffic conditions. This may lead to the conclusion which secondary actions which aim at improving the traffic's conditions with certainty would help to reduce CO and HC emissions, in this traffic's conditions is necessary also, to do use of the others devices for to reduce the NOx emissions which increase in this condition.

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