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Automotive Emissions — The Brazilian Control Program

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ABSTRACT

The fast and continuous urbanization trend observed in Brazil since the early 1960's associated with a chronic lack of adequate mass transport systems and increasing individual motorization has led the major cities to traffic congestion and motor vehicle air pollution.

In an effort to address this problem, the Federal Government, through the National Environment Council (Conselho Nacional do Meio Ambiente - CONAMA), approved on May 6th, 1986, the Resolution nº 18, which establishes nationwide the automotive emissions control program named PROCONVE. This paper outlines the most important points of the program, discusses its feasibility and presents the first achievements.

SINCE THE END OF THE 1950's, the world has become aware of the negative impact which automotive emissions could have upon the environment. Due to the considerable motor vehicle contribution to air pollution in Southern California, the first meaningful automotive emissions legislation was enacted by the State of California in the early 1960's. Further regulations, that progressively cut down emissions followed quickly and were also adopted elsewhere in the United States.

The recognition that motor vehicle generated air pollution has been imposing socioeconomic costs and environmental damage led governments of various countries to take action through the enforcement of emission control programs. Japan started its control program in 1966, the ECE countries, Sweden and Canada in 1971, the United Kingdom and Australia in 1972 and Finland in 1975 (1)*.

As a result, newer vehicles are significantly cleaner than the uncontrolled predecessors reaching, in certain countries, emission reduction levels above 90% and therefore contributing to air quality improvements.

In Brazil, air pollution from motor vehicles has become a public issue in the mid 1970's. The fast, unplanned and continuous growth of many Brazilian cities, especially since the early 1960's, associated with a chronic lack of adequate mass transport systems and increasing individual motorization, created the same typical scenario of traffic congestion and air pollution which has been observed in many parts of the world.

AIR POLLUTION FROM MOTOR VEHICLES

Important Brazilian metropolitan areas like São Paulo, Rio de Janeiro, Belo Horizonte, Salvador, Recife, Porto Alegre and Curitiba, with a population of approximately 40 million people, have been experiencing increased air pollution from motor vehicles along the years, being São Paulo probably the most serious case. It has been observed that when one considers carbon monoxide, photochemical smog, nitrogen dioxide, hydrocarbons and particulates, São Paulo has one of the most severe vehicle related air pollution problems in the world (2), since all these pollutants exceed the air quality standards simultaneously in this area. The air quality data generated by CETESB, the Environment Control Agency for the State of São Paulo, supports this conclusion. Carbon monoxide (CO) and ozone (O_3) ambient concentrations routinely exceed the air quality standards, as shown in Tables 1 and 2. Peak concentrations have reached 26.7 ppm (8-hour average) for CO and 226.0 ppb (1-hour average) for O_3. Table 3 shows the Bra-

* Numbers in parentheses designate references at end of paper.

zilian air quality standards for the regulated pollutants and Table 4 the air pollution acute episode criteria for the State of São Paulo.

Table 1 - Carbon Monoxide - Automatic and Manual Network - ppm

Sampling Site	Standard Exceedances (Number of Days)										1^{st} - 8h Maximum				
	NAQS (8h)					Attention Level (8h)									
	1981	1982	1983	1984	1985	1981	1982	1983	1984	1985	1981	1982	1983	1984	1985
Correio	282	257	204	167	108	98	37	34	12	10	26,7	20,8	20,3	18,4	19,3
Pq. D.Pedro	17	5	1	1	8	4	0	0	0	0	20,1	10,6	9,5	9,2	14,1
Mooca	10	0	4	0	0	0	0	0	0	0	15,0	7,9	10,5	5,7	6,2
Congonhas	65	69	21	1	7	9	8	0	0	2	22,8	20,3	14,7	11,1	17,5
Cerqueira Cesar	52	32	100	78	42	7	2	5	4	1	17,8	16,5	18,4	16,1	15,9

NAQS - National Air Quality Standard

Table 2 - Ozone - Automatic Network - $\mu g/m^3$

Sampling Site	Standard Exceedances										1^{st} - 1h Maximum				
	NAQS (Number of Hours)					Attention Level (No. of Days)									
	1981	1982	1983	1984	1985	1981	1982	1983	1984	1985	1981	1982	1983	1984	1985
Pq. D.Pedro	47	40	5	10	27	8	10	1	3	4	294	267	216	220	142
Mooca	93	30	40	28	89	19	4	9	5	4	443	253	347	310	142
Congonhas	10	2	36	13	13	3	2	7	4	2	321	255	363	214	121
Lapa	45	6	9	82	63	10	6	2	19	10	345	310	245	527	153

NAQS - National Air Quality Standard

Table 3 - National Air Quality Standards

Pollutant	Sampling Time (h)	Standard ($\mu g/m^3$)	Reference Method
Total Suspended Particulate	24*	240	Hivol Sampler
	AGM**	80	
Sulfur Dioxide	24*	365	Pararosaniline
	AAM***	80	
Carbon Monoxide	1*	40.000	NDIR****
	8*	10.000	
Photochemical Oxidants (as ozone)	1*	160	Chemiluminescence

* Not to be exceeded more than once a year
** Annual geometric mean
*** Annual arithmetic mean
**** Non dispersive infra red

Table 4 - Air Pollution Acute Episode Criteria for the State of São Paulo

Parameter	Levels		
	Attention	Alert	Emergency
Sulfur dioxide ($\mu g/m^3$)-24h	800	1600	2100
Total Suspended Particulate (TSP) ($\mu g/m^3$)-24h	375	625	875
SO_2 x TSP $(\mu g/m^3)^2$-24h	65×10^3	261×10^3	393×10^3
Carbon Monoxide (ppm) - 8h	15	30	40
Photochemical Oxidants (as O_3) $\mu g/m^3$ - 1h	200	800	1200

Although Brazil has not established air quality standards for non methane hydrocarbons (NMHC) and nitrogen oxides (NO_x) yet, recorded peak concentrations for these pollutants in São Paulo City are 4 ppm (6-9 a.m. average) and 509 ppb (annual average), respectively. These values represent about 17 times for NMHC and 5 times for NO_x the U.S. air quality standards. Despite the fact that motor vehicles are not the major source of particulates (PM) and sulfur oxides (SO_x) in the São Paulo Metropolitan Area (SPMA), their contribution is still significant, being estimated for 1985 an emission of 77,700 t/year of SO_x and 20,800 t/year of PM.

Although these emissions represent, on a mass basis, only 20% to 30% of the corresponding total emissions in the SPMA, vehicle generated gases and particulates are discharged at street level, therefore public exposure to them is generally greater than it is to discharges from industrial stacks. Additionally it is worthy of note that the PM emitted by motor vehicles, due to its tiny size, chemical properties, emission at street level and persistence in the atmosphere, may pose a greater risk to the public health than some of the particulates generated by industrial sources.

Table 5 - Motor Vehicle Emission Inventory for the São Paulo Metropolitan Area - 1985

Pollutant	Emission (10^3t/year)
CO	1,308.4
HC	195.9
NO_x	200.3
SO_x	77.7
PM	20.8

A different approach to evaluate the severity of motor vehicle emissions on air quality, is the analysis of the public perception of the situation. In 1985, CETESB conducted in São Paulo City a public survey which shows that 95% of the interviewed population consider the air polluted and that motor vehicles contribute significantly to this pollution. Furthermore, 89% agreed that it is necessary to establish an emission control program for motor vehicles in order to improve air quality.

Precise evaluation of automotive contribution to air pollution in most Brazilian cities has not been possible because the existing air quality monitoring networks are either inadequate or insufficient for this purpose. However, based on available data regarding motor vehicle fleet, growth rate, traffic conditions and emissions, the motor vehicle generated air pollution is probably severe in the major cities and may become a problem in the foreseeable future in many other cities if no actions are taken to control emissions. Therefore, to cope with this problem, CETESB presented to the federal government a proposal for the establishment of an emission control program. This proposal was submited for analysis to all interested parties and after a discussion which took two years, it was modified in some points, becoming the national automotive emission control program.

THE EMISSION CONTROL PROGRAM

The Brazilian automotive emission control program, named PROCONVE, was established by the National Environment Council (Conselho Nacional do Meio Ambiente - CONAMA) on May 6th, 1986, and it is regulated by the Resolution No. 18.

The program strategy is based on successfull international experience and can be defined by the following key points:

. Only new engines and vehicles are required to comply with the established emission limits.

. Emission limits that progressively become more stringent are phased in according to a schedule which is based on the state of technology in Brazil and the international experience.

. Emission test methodologies follow international trends and therefore promote standardization.

. Prototype, assembly-line and aftermarket parts certification is required in order to guarantee product quality and conformity.

. Manufacturers are required to warrant emission conformity in order to guarantee the emission control systems durability.

. Adjustable components which may significantly affect emission are required to be sealed by the manufacturer or incorporate inviolable limiting devices for the permissible gauging range in order to avoid maladjustements during tune-ups.

. Manufacturers are required to present, semesterly, emission data from their quality control programs; based on this data, production approval for certain engines or vehicle configurations may be withdrawn, therefore optimizing the certification process.

. State or City Administrations are authorized at their discretion to implement inspection and maitenance programs (I/M) in order to verify the effectiveness of the emission control systems in consumer use and to foster adequate maitenance.

. New types of fuels and modification of present fuel specifications may be adopted after approval by the Administration.

. The Administration may order a recall, if through special checks or I/M programs it is verified that adequately mantained vehicles in-use do not comply with the emission limits. All costs involved in such action shall be borne by the manufacturer.

. Due to the use of ethanol as an automotive fuel, the Administration may establish emission limits for the so-called unregulated compounds, such as aldehydes, alcohols and other organic compounds. As for hydrocarbons, this class of pollutants is defined as the total amount of organic substances, including unburned fuel fractions and combustion byproducts, occurring in exhaust gas, and which are detected by the flame ionization detector.

. To promote public awareness with respect to the program and the issue of air pollution by motor vehicles, the manufacturers are required to furnish specifications and recomendations to the owner, the service network and to the public through the owner's and services guides, the media and labels placed on all vehicles.

. The National Petroleum Board (CNP) is requested to establish a program for reducing the total sulfur content from the diesel fuel, to specify and oversee the total exclusion of lead in the ethanol/gasoline blend and to ensure that ethanol is not contaminated by lead during transport or storage.

For the purposes of management and permanent evaluation, the National Environment Council instituted the "PROCONVE Follow-Up and Evaluation Committee", coordinated by the Special Secretary for Environment Affairs (SEMA) and composed of eleven top government officials which have the competence to identify and propose measures for optimizing the program, deliberate on penalties to be imposed, supervise and control the enforcement of the program, grant exemptions, waivers, etc.

EMISSION TEST PROCEDURES

The emission test procedures standardized in Brazil and summarized in Table 6, are versions of actual international procedures and represent a combination of the state of the art and cost effectiveness.

Table 6 - Emission Test Procedures Adopted in Brazil

Type of Emission	Type of Vehicle	Emission Test Procedure
Exhaust	LDV - Otto Engine	U.S. - 75 FTP
	LDV - Diesel HDV - Engine	U.S. "13 Mode" FTP European Full-Load Steady State Test Procedure(smoke)
	HDV - Otto Engine	U.S. "9 Mode" FTP
Evaporative	LDV - Otto Engine	U.S. SHED FTP

- For the light duty vehicles powered by Otto engines, the U.S.-75 test procedure was chosen because it better reflects actual driving conditions than the European or Japanese emission test, the sampling and analytical systems are more suitable for alcohol and gasohol fuels than the European emission test and because its gradual adoption by a number of countries, it may well become the international reference test procedure.

In contrast to the European emission test, the adoption of the U.S. procedure represents the confidence that considerable investments in emission laboratories will not be lost in a few years due to obsolescence.

For the Diesel engines, wheter they power light duty or heavy duty vehicles, the U.S. "13-mode" and the European "full load steady state" engine test procedures were chosen for gaseous emissions and smoke, respectively. These emission tests are presently adopted in Europe (the European version has some differences from the U.S. test) and, although they are not as sophisticated as the U.S. transient test, can be adapted to existing engine laboratories. The European experience has shown that these tests, despite the fact that they do not adequately represent actual engine operating conditions, can be successfully used to develop emission limits which cut down the gross exhaust pollution. At this point, it is important to note that Diesel vehicles are used in Brazil mainly for commercial purposes and mass transport and represented, in 1985, approximately 8% of the total motor vehicle fleet.

Due to the European experience with the 13-mode test, CETESB is evaluating the use of the European version in place of the U.S. version.

In a lower priority for emission control, we have the heavy duty vehicles powered by Otto engines, because they represented, in 1985, only 1% of the total motor vehicle fleet and there are no signs that this percentage may increase substantially in the near future. Therefore, the emission test procedure adopted for the Otto engines is the U.S. "9 mode", simply because it utilizes the same basic equipment and instruments needed for the "13 mode" test.

STANDARD FUELS FOR THE EMISSION TESTS

The Brazilian emission limits are being developed with the help of the previously referred test procedures and shall be attained in official tests by vehicles or engines fueled with the standard emission test fuels presented in Tables 7 and 8.

These fuels were specified in such a way as to represent the typical Brazilian commercial fuels, but with tighter tolerances. The gasoline - anhydrous alcohol blend shall be prepared from the corresponding test fuels, in the proportion of 22,0 ± 1,0 of alcohol, by volume.

Table 7 - Standard Alcohol Fuels (CNP Resolution No. 1 - 1985)

I t e m	Anhydrous Ethanol	Hydrated Ethanol	Test Method
Alcohol grade at 20°C, °INPM	99.5 ± 0.2	93.2 ± 0.4	No. 7 - 1982
Residue, mg/l, maximum	50.0	50.0	
Total acidity, mg/l, maximum	20.0	20.0	
Aldehydes, mg/l, maximum	-	60.0	
Esthers, mg/l, maximum	-	80.0	
Higher alcohols, mg/l, maximum	-	60.0	
Alcalinity	negative	negative	
Copper, mg/kg, maximum	0.03	-	
Sodium, mg/kg, maximum	2.0	2.0	Flame photometer
Sulfate, mg/kg, maximum	2.0	2.0	Gravimetric
Conductivity, μS/m, maximum	600.0	600.0	Conductivitimeter
Density at 20°C, kg/m^3	790.9 ± 0.6	809.4 ± 1.1	NBR-5992
Aspect	clean and without suspended particles	clean and without suspended particles	Visual

Table 8 - Standard Gasoline (Brazilian Standard NBR-8669 - December 1984)

I t e m	Specification	Test Method
Motor octane number	73 - 75	ASTM D-2700
Sensitivity	3 minimum	-
Tetraethyl lead, ml/l	0.4 maximum	ASTM D-3237
Distillation range IBP, ^{0}C 10% point, ^{0}C 50% point, ^{0}C 90% point, ^{0}C E.P., ^{0}C	35 - 50 55 - 71 78 - 98 135 - 155 170 - 205	ASTM D-86
RVP at 37.8^{0}C, kPa	29.42 - 53.94	ASTM D-323
Sulfur, weight %	0.15 maximum	NBR-6563
Gum, mg/100 ml	5 maximum	ASTM D-381
Hydrocarbon Composition Olefins, volume % Aromatics, volume % Saturates, volume %	 20 maximum 40 maximum to be recorded	
C/H ratio	to be recorded	
Relative density, 20^{0}C/4^{0}C	to be recorded	NBR-7148
Copper corrosion, 3h at 50^{0}C	1 maximum	ASTM D-130
Induction period, min.	1500 minimum	ASTM D-525
Aspect	clean and without suspended particles	visual

The standard diesel fuel specification is being revised, therefore, it is not presented in this paper.

THE EMISSION LIMITS

The emission limits for light duty vehicles powered by Otto engines and heavy duty vehicles are presented in Tables 9 and 10,respectively. For the light duty vehicles, the emission limits were established under the premise that by 1999, CO concentrations in ambient air should.conform to the air quality standards in the SPMA. Therefore, for this pollutant, the proportional Rollback model was used to define the limits until 1997. For the other two pollutants, the limits were established according to an engineering analysis of possible emission reductions that can be achieved with present emission control technologies. These reductions were correlated with the already defined CO emission limits. The idle CO emission limits were based on the best available information regarding the control of this type of emission and were established because many Brazilian cities have a congested traffic. Furthermore, they will provide a baseline for maitenance and future inspection and maitenance programs. The smoke emission limits were established according the criteria of best proven control strategy for this pollutant. The European experience with smoke control has been more successful than others.

Table 9 - Emission Limits for Brazilian Alcohol and Gasoline Light Duty Vehicles

Type of Emission	Effective Date	Remarks	Emission Limits			
			g/km			%
			CO	HC	NO_x	Idle CO
EXHAUST	Jun 1st, 88. Jan 1st, 89. Jan 1st, 90. Jan 1st, 92.	Brand new vehicle configurations 50% of sales is the minimum required 100% of sales except LDT Only LDT	24,0	2,1	2,0	3,0
	Jan 1st, 92.	100% of sales except LDT	12,0	1,2	1,4	2,5
	Jan 1st, 97.	All LDV	2,0	0,3	0,6	0,5
Evaporative	Jan 1st, 90.	All LDV	-	g/test 6,0	-	-
Crankcase	Jan 1st, 88.	All LDV	emission shall be nill under any engine operating conditions			

Note: LDV - light duty vehicles
LDT - light duty trucks

Table 10 - Emission Limits for Brazilian Heavy Duty Vehicles

Type of Emission	Effective Date	Remarks	Emission Limits
EXHAUST	Oct. 1st, 87.	only for urban buses powered by Diesel engines	k = 2,5 (smoke)
	Jan. 1st, 89.	all vehicles powered by Diesel engines	
	to be proposed until December 31, 1988.	- only for vehicles powered by Diesel engines	k = 2,0 (smoke)
		- for vehicles powered by either Diesel or Otto engines	shall be proposed until December 88 for CO, HC, NO_x
Evaporative	to be proposed	only for vehicles powered by Otto engines	to be proposed
CRANKCASE	Jan. 1st, 88.	only for urban buses powered by Diesel engines	emission shall be nil
	to be proposed until Dec. 31, 1987	all vehicles powered by Diesel engines	under any engine
	Jan. 1st, [illegible].	all vehicles powered by Otto engines	operating conditions

The emission limits shall be warranted in writing by the manufacturer according to the requirements summarised in Table 11, as follows:

Table 11 - Emission Limits Warranty

Type of Vehicle	Warranty Requirements	Remarks
Light duty vehicles	80,000 km/5 years whichever occurs first	Testing procedures to be established; in the meantime, the warranty may be replaced by a 10% reduction in the emission limits, except for idling CO.
Heavy duty vehicles	160,000 km/5 years whichever occurs first or equivalent results on a dynamometric testing procedure	

Notes:

1) The light duty vehicles powered by Diesel engines shall follow the same prescriptions established for the heavy duty vehicles.
2) The smoke limit was stablished according to the European procedure which is based on the equation $c = k\sqrt{G}$, where c is the carbonic concentration, in g/m^3, G is the exhaust gas flow in l/s and k is a constant that represents the smoke level.

EMISSION REDUCTION

The effect of the PROCONVE on exhaust emission from light duty vehicles (Otto engines) has been evaluated by CETESB for the São Paulo Metropolitan Area (3).

The study, based on the temporal evolution of the 1984 emission inventory data, according to ten fleet growth scenarios, indicates potential emission reductions of 63% for CO, 50% for HC and 35% for NO_X expected by 1999.

If, for the same study scenarios, instead of the established emission limits, Brazil would have adopted the 1981 U.S. emission limits, to be enforced in 1987, then the potential emission reductions would be 90% for CO, 85% for HC and 67% for NO_X. Although this hypothesis might be highly desirable, it would not be feasible mainly due to the present unavailability of advanced emission control technology in Brazil and due to the necessity to adapt, in a very short time, emission control systems developed elsewhere for the Brazilian vehicles and fuels.

As for the evaporative emissions, it can be said that emission reduction for certain vehicle configuration will be higher than 80%.

As far as Diesel smoke emissions are concerned, it is expected that certain Diesel engine manufacturers will have to bring down smoke levels by approximately 25% in order to meet the first control stage requirements.

Although detailed emission reduction forecasts for all pollutants are not available yet, it can be inferred that automotive emission control will have a positive impact on air quality either through corrective action in the polluted areas or through preventive action in the unpolluted areas.

THE FEASIBILITY OF THE CONTROL PROGRAM

When considering the establishment of a motor vehicle emission control program, especially in a developing country, one has to analyze local conditions in order to verify the possibilities of adopting, successfully, the international experience which has been acquired in the so-called industrialized countries. In the case of Brazil, this is possible because there is a well established motor vehicle industry, capable of designing and producing control systems that have proved to be efficient, durable and cost-effective elsewhere.

Actually, the Brazilian motor vehicle industry has been exporting engines, vehicles and components to countries like the U.S.A., Canada and Sweden which have ongoing emission control programs. In addition, Brazil represents a market of about one million vehicles/year which, according to industry sources, may reach 1,5 million vehicles/year in 1990. Such a considerable market has certainly caught the attention of emission control manufacturers.

Furthermore, the alcohol fuel program has fostered fast technological development which resulted in new advances in materials engineering, engine optimization, fuel economy and some emission reduction. Due to the blend of 22% ethanol to gasoline, lead levels have been substantially lowered and the impact of reduced lead emissions on air quality can be seen in Figure 1. The possibility of having unleaded fuels is real within a short period of time, making the use of catalytic converters or other lead sensitive control systems possible.

As for the Diesel fuel, the sulfur content is still high, being the national average 0.7% by weight. However, desulfurization plants are being built and planned, so, it is expected that in few years, low sulfur Diesel fuel will be available. Unfortunately, sulfur is not the only problem; Diesel fuel specifications need to have tighter tolerances and fuel quality has to be improved. Therefore, a working group involving the oil industry, the Diesel vehicle manufacturers and government agencies has been established to discuss the possibilities of upgrading the Diesel fuel.

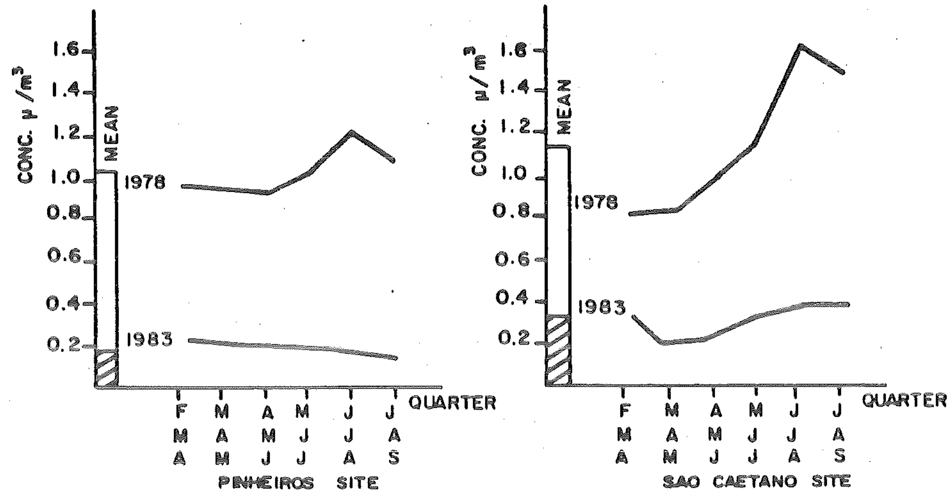

Fig. 1 - Lead quarterly average concentrations at two sampling sites in SPMA during 1978 and 1983

Another point to be considered is the in-use vehicles maitenance. Generally speaking, Brazilian service personnel are poorly trained having hands on experience rather than adequate training. Therefore, a training program directed to improve the mechanics expertise and to get them acquainted with emission control systems, needs to be implemented.

Although at present there are no official inspection and maitenance programs in Brazil, it is felt that certain critical areas, like the SPMA, will have to begin with such programs in a few years.

One additional point of interest is the cost of the emission control systems for the consumer. To this question, we would like to refer again to the public survey conducted in São Paulo City. When asked about the willingness to pay 10% more for a new vehicle which would be equiped with "filters" to reduce pollution, 79% of the interviewed people said they would pay the extra cost in order to have less pollution, 17% said no and 4% said they did not have any opinion. The "10%" value was arbitrarily chosen in order to give an "impact" to the question. Nevertheless, it is expected that emission control systems will add no more than 5% to the vehicle cost.

Considering this broad picture, it is safe to say that Brazil has the basic conditions to adopt an emission control program comparable to present similar foreign programs.

FIRST EFFECTS OF THE CONTROL PROGRAM

The PROCONVE, as a recently established program, has not had the time to cause any positive impact on air quality yet, however, it produced some side effects that can be reported already. The first effect worthy of mention is the removal of certain barriers which set apart the environment control people and the industry people. It is clear that only a combined effort of industry and government can lead to a successful program. A second effect is the progress in technological expertise which is being observed. In fact, considerable efforts in human resources training are presently being made, particularly by the industrial sector, with a significant impact on Brazilian automotive engineering. Another important effect is the practical experience which is being acquired due to the requirement of a semesterly report of "typical emission values". To prepare such a report, the industry people have to pay attention to emissions, a fairly new topic to a great number of engineers. Besides the training effect, which will be highly valuable during the emissions control stage of the program, important data come out from these reports giving to the government a more comprehensive panorama of the state of emissions in Brazil. An effect which cannot be overviewed is the effect on the economy. In fact, the PROCONVE created a new market for equipment, instruments, parts, systems and services related to R&D, emission testing, quality control, emission control and vehicle maitenance.

Furthermore, the PROCONVE can be a key factor to promote or expand Brazilian automotive exports, therefore contributing to the balance of payment.

Other effects are being observed, such as research of non-noble metals for catalytic converters but, by now there is no available information about this work.

CONCLUDING REMARKS

The PROCONVE is at its initial stage and it is not the authors' intention to claim that it is perfect or that it should not be modified in the future. In fact, a lot of work is necessary from the government, the motor industry and research institutes in order to make it a reality. Public and political support are also essential. The environment is not a gabarge box with infinite capacity, in fact, it is just the other way round. This is true for both industrialized and developing countries. The PROCONVE is a feasible program for Brazil and certainly similar programs may be adopted by other developing countries.

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