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ABSTRACT

The continued expansion of alcohol use in Brazil, to replace gasoline as fuel for Otto internal combustion engines, has led to the technological development of these engines. However, despite the progress achieved in fuel economy, driveability, corrosion resistance, etc., no comparable progress has been achieved in air pollutants emission control.

This paper presents an overview of the alcohol automotive use in Brazil and discusses its air pollution related aspects.

CONSIDERATION ON THE USE of alcohol as an automotive fuel is as old as the invention of the internal combustion engine itself. Nikolas A. Otto, in his early engine studies in 1897, used neat alcohol.

In Brazil, some experiments with neat ethanol in Otto cycle engines were reported in 1923 and 1925. In 1931, 5% blend of anhydrous ethanol with imported gasoline was made compulsory. In 1938, the addition of anhydrous ethanol was extended to gasoline refined in Brazil. During the 1942/1956 period, a variable content of anhydrous ethanol was blended with gasoline in northeastern Brazil, being 40% the maximum ethanol content reported. In 1973, due the high increase in oil prices, the Ministry of Industry and Commerce (MIC) contracted the Aerospatial Technical Center (CTA) to carry out a research program in order to establish the technical feasibility of using alcohol in internal combustion engines. In 1975, after the first positive results with Otto cycle engines, an experimental fleet of government-owned vehicles, equipped with gasoline engines converted to neat ethanol use, started on road tests.

Faced with a high oil import dependence, with the sharp decrease in world sugar prices and backed by the positive results with the alcohol fueled engines, the Federal Government launched in November 1975 the National Alcohol Program (PNA) which has been under continued expansion and seems to follow an irreversible way.

Exception made to few areas where alcohol is not available yet, every Otto cycle engine in Brazil is presently (August 1984) either fueled with a 20% anhydrous ethanol/gasoline blend (here after referred as to 20% gasohol) or with neat ethanol.

THE DEVELOPMENT OF THE ETHANOL FUELED ENGINE

The development of the Otto cycle neat ethanol fueled engine has been fast if compared to the decades of research that have been spent developing the gasoline fueled engine.

The first ethanol engine generation was developed during the 1975/79 period. These engines were basically gasoline engines converted to neat ethanol use. The conversion was made by research institutes and selected engine rebuilders under CTA's close supervision. The main modifications consisted in the use of higher compression ratios, carburetor recalibrations, sparktiming optimization and redesign of the intake manifolds.

In addition, a small gasoline tank was included in order to provide gasoline injection during starting operation in low ambient temperatures.

By the end of 1979, there were about 700

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vehicles running on neat ethanol in Brazil and MIC required governmental institutions to replace their gasoline fueled vehicles by ethanol fueled vehicles.

The second ethanol engine generation was developed during the 1979/80 period when car manufacturers developed and put on for sale models equipped with engines designed to run on neat ethanol. The manufacturers had to attend the Federal Regulation that states that engines running on neat ethanol cannot be lower than 25% in fuel economy over the same engine designed to burn gasoline. Therefore, a technological effort had to be made. Cylinders, cylinder heads, valves, valve seats, pistons, rings, intake manifolds, carburetors and electrical systems were designed for ethanol use. Special corrosion resistant materials and coatings were used in the fuel system and filters were mounted in the fuel supply line to avoid gum formation. However, some of the assembly line models still suffered from corrosion, cold start and driveability problems.

The third ethanol engine generation has been under development since 1981 and the result has been positive, up to now. The use of electronic ignition systems, higher compression ratios (up to 12:1), new carburetors, improved corrosion-resistant coatings and materials, automatic cold start systems and over drive gear improved engine power, driveability, fuel economy and cold start capability. Furthermore, it has been claimed by the car manufacturers that maintenance is equivalent to the 20% gasohol fueled vehicles.

The general public has reacted favourably towards these improvements and sales of alcohol vehicles, mainly passenger cars and station wagons, have sharply increased. In 1983, about 80% of the light-duty vehicle sales were ethanol vehicles. It has to be noted, however, that lower taxes and fuel price policy have been a big incentive for the increased use of the ethanol fueled vehicles.

Fuel economy for the 1983 light-duty ethanol vehicles varies from 5.0 to 8.7 km/l (11.7 to 20.4 mpg) for EPA city driving cycle and 8.0 to 12.0 km/l (18.8 to 28.2 mpg) for EPA highway driving cycle (1).

THE USE OF ETHANOL-GASOLINE BLENDS

The average anhydrous ethanol content in gasoline in Brazil during the 1979-1983 period is presented in Table 1:

Table 1 - Average Content of Ethanol in Gasoline

Year	Ethanol Content (%)
1979	14.0
1980	17.0
1981	12.0
1982	20.0
1983	20.0

Source: (2, CETESB)

The conversion of gasoline engines to operate on ethanol-gasoline blends required only minor modifications such as carburetor recalibrations, spark-timing optimization and the use of corrosion-resistant materials and coatings in the fuel system, as well as neoprene fuel pump diaphragm. Public acceptance to the use of ethanol-gasoline blends has been good and, apart from the seasonal variability of the ethanol content that in some cases affected engine power, driveability and fuel economy, no other major problems have been reported.

Fuel economy for the 1983 light-duty 20% gasohol vehicles varies from 6.2 to 12.3 km/l (14.6 to 28.9 mpg) for EPA city driving cycle and from 9.7 to 17.1 km/l (22.8 to 40.2 mpg) for EPA highway driving cycle (1).

AIR POLLUTION

When ethanol was considered a feasible energy alternative in the mid-1970s, the immediate environmental concern in Brazil was water pollution and land mismanagement. In fact, a rush to use sugar cane for ethanol production could pose an environmental risk because liquid wastes from the alcohol distilleries might create serious water pollution problems if dumped untreated into rivers, lakes, etc., and land mismanagement would trigger ecological disruption.

When referring to air pollution from the ethanol vehicles, the predominant idea was that ethanol would be a pollution-free fuel. Some people would even bend down next to the exhaust pipe of an accelerating or idling ethanol vehicle and inhale deeply the exhaust gases in order to prove its cleanliness.

Nevertheless, the pollution-free fuel concept started to be questioned in 1979 when the sweet pungent odor, characteristic of the neat ethanol vehicles exhaust, was easily noticeable in the areas these vehicles were running. This was the first public evidence that alcohol vehicles were not pollution-free.

In 1980, a preliminary emission test (3) was performed with a Volkswagen vehicle equipped with a 1300 cm^3, gasoline converted to neat ethanol, air cooled engine at CETESB's Vehicle Test Laboratory. Carbon monoxide (CO) and Total Aldehydes (R-CHO) were measured at constant speeds and the results are compared in Table 2 and 3 with data obtained from a gasoline (5% anhydrous ethanol content) vehicle of the same model and tested at the same conditions.

These results showed that ethanol is by no means a pollution-free fuel. Actually, it is more polluting than gasoline as far as aldehydes are concerned. Another set of tests conducted by CETESB in 1980 (4) with 8 ethanol vehicles and 6 gasoline (5% anhydrous ethanol content) vehicles, showed that the alcohol vehicles emit less CO and total hydrocarbons* (HC) and more R-COH and nitrogen dioxides (NOx) than the gasoline vehicles.

Table 2 - CO Emission for Brazilian Volkswagen with Neat Ethanol and Gasoline - (%)

SPEED (km/h)	LOADED(*) Gasoline Vehicle	LOADED(*) Ethanol Vehicle	UNLOADED(*) Gasoline Vehicle	UNLOADED(*) Ethanol Vehicle
30	2.6	1.1	2.5	2.7
40	2.5	0.5	2.3	1.4
50	1.9	1.0	2.1	1.0
60	1.1	1.2	1.6	0.6
70	2.0	0.7	1.3	1.4
80	1.0	0.5	0.9	1.1
90	1.1	0.5	0.6	0.5
100	1.2	0.7	0.4	0.3

Table 3 - Total Aldehyde (**) Emission for Brazilian Volkswagen Fueled with Neat Ethanol and Gasoline - (ppm)

SPEED (km/h)	UNLOADED(*) Gasoline Vehicle	UNLOADED(*) Ethanol Vehicle
50	80	111
60	89	127
70	109	164
80	191	203

(*) Loaded and unloaded are dynamometer simulation conditions for 5% inclined road and for horizontal road respectively.

(**) R-CHO were measured by the Bissulphite/Titration Method.

Source: (3)

The vehicles were tested in accordance to the EPA 1975 test procedure and it was assumed they would represent in-use conditions. Therefore, no tune-up was performed prior to the tests. The results of this study are presented in Table 4.

Due to the high emission of R-CHO from both ethanol and 20% gasohol vehicles, CETESB's Air Quality Department surveyed R-CHO ambient concentrations in São Paulo City, from July 1980 until June 1981 (5). Also CO and ozone (O_3)

Table 4 - Average Emission Results from Brazilian Vehicles Fueled with Neat Ethanol and Gasoline - (g/km)

Pollutant / Fuel	CO	HC(*)	NO_x	R-CHO(**)
Ethanol	14.38	1.23	1.29	0.157
Gasoline	41.69	3.91	1.14	0.029
Ethanol/ Gasoline Ratio	0.34	0.31	1.13	5.41

(*) HC were measured by a Flame Ionization Detector (FID) calibrated with propane.

(**) R-CHO were measured by the MBTH/Colorimetric Method.

Source (4)

were monitored in order to indicate respectively traffic and photochemical activity. The R-CHO values, 24-hour average, are presented in Table 5 for the four monitoring stations and were obtained by the MBTH/Colorimetric Method. Considering that the samples were collected over a 24-hour period it has to be noted that the R-CHO values are very high. Studies conducted in California during severe smog episodes indicate similar ranges of R-CHO but for short sampling periods, i.e. equal or less than one hour (6,7). By this time, São Paulo City had about 1,650,000 light-duty vehicles. Of this number, 50,000 were ethanol fueled and 1,600,000 were 20% gasohol fueled.

The data indicate Correio station as having the highest monthly average R-CHO readings. In fact, this was not a surprise because this station is located in a traffic-saturated area, whereas the other stations are located in areas with lower traffic densities. Figure 1 shows the variation of CO and R-CHO in the monitoring stations.

As can be seen, stations Correio and Congonhas, which are closer to the traffic lines, show a similar tendency for CO and R-CHO. Therefore, it may be concluded that ethanol and gasohol fueled vehicles are a major source of primary aldehydes, which are expected to be precursors of photochemical activity. Unfortunately, the study failed to evaluate the photochemical activity of these emissions.

In general, as aldehyde concentrations in the air increase, various effects varying from irritation of exposed skin and tissues to pulmonary edema with respiratory failure. It may be observed there are also strong evidences of neoplastic activity to aldehyde exposure (8) A study conducted by the National Institute of

Table 5 - Total Aldehydes Ambient Concentrations in São Paulo City (ppb)
July 1980/June 1981

Station	Correio			Parque D. Pedro			Mooca			Congonhas		
Month	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.
July/80	40	57	27	20	48	11	14	31	7	24	48	16
August/80	42	66	20	20	42	9	20	63	6	38	159	12
September/80	36	66	25	24	44	10	11	20	6	23	36	12
October/80	38	57	28	18	32	10	13	28	5	25	36	18
November/80	38	53	19	15	24	5	12	27	7	24	30	11
December/80	52	61	40	20	24	14	18	46	8	24	28	15
January/81	42	57	20	18	86	6	15	29	5	22	34	5
February/81	43	50	34	25	69	11	15	28	9	26	33	20
March/81	37	52	19	18	41	10	14	24	8	26	35	12
April/81	38	51	29	17	26	13	14	37	8	28	35	18
May/81	44	55	26	22	34	14	18	28	8	34	63	16
June/81	58	99	22	25	48	13	21	43	8	28	46	14

Source: (5)

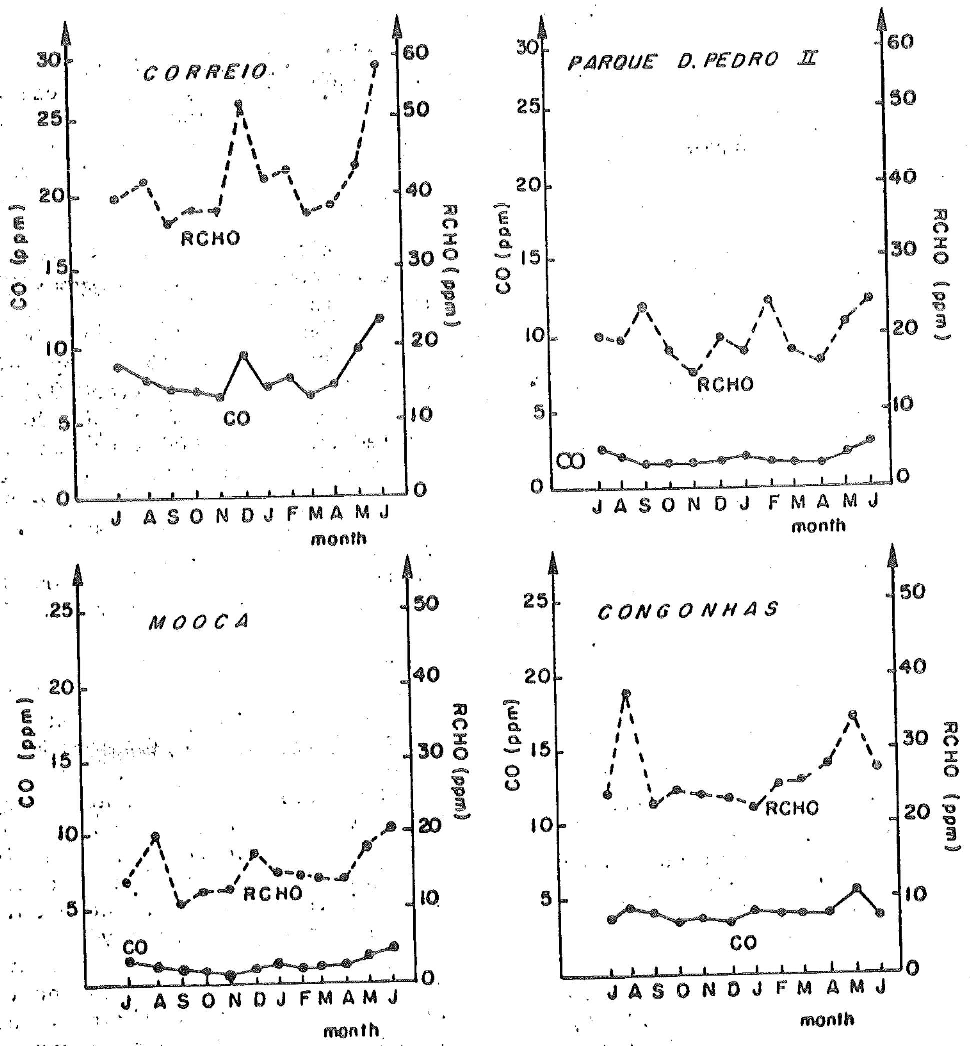

Fig. 1 - Average Monthly Concentrations of Total Aldehydes and CO in São Paulo City - July 1980/June 1981

Source: (5)

Technology (INT) (9) evaluated the response of mice and plants (Marantacea and Canavalia Sp) to 30 ppm of acetaldehyde. As it is known, acetaldehyde is emitted in considerable amounts from ethanol fueled engines. After an 8-hour period of exposure, the 10 mice examined presented various respiratory problems, alveolar emphysema being the most frequent. After a 16-hour period of exposure, some of the animals died from acute respiratory insufficiency. The others when examined showed severe respiratory problems. The plants showed gradual mutations with increased time exposure and died after 32 hours.

Although 30 ppm may sound high for ambient concentrations, acetaldehyde concentration may well build up to this level in poorly ventilated garages.

Many studies all over the world have documented toxicological effects of aldehydes, but because ambient air is such a complex mixture of gases, vapors and particulates, the interaction of aldehydes with the other atmospheric species may lead to synergetic health effects.

The fact that ethanol is a pollution-reducing fuel must be recognized if sulfur, lead, aromatic hydrocarbons and carbon monoxide emissions are under consideration.

Ethanol itself does not contain sulfur and does not need lead to boost its octane rating but, because it is denatured with gasoline (up to 3% by volume), very low emissions of sulfur and lead (in case the gasoline contains lead) will occur. Ethanol is also used as a lead substitute to boost gasoline octane rating. Regular Brazilian gasoline has about 73 MON (Motor Octane Number) and when 20% by volume of anhydrous ethanol is blended with this gasoline, MON goes up to 81. Therefore, lead emission from 20% gasohol can be cut down to zero.

The use of an octane booster such as ethanol, allows the oil refineries to produce gasoline with a low aromatic content. This is certainly a benefit because aromatics that are emitted from gasoline exhaust emissions, such as Benzene, Toluene and Xylene are known carcinogens and are considered to be precursors of photochemical oxidants. However, the gain in reducing aromatics has to be balanced against the increase in oxygenated compounds such as aldehydes and alcohols which are also precursors of photochemical oxidants and some of them, like formaldehyde, are known carcinogens too. As far as CO emission is concerned, the use of ethanol either neat or blended with gasoline, has reduced the emission of this pollutant from Brazilian vehicles. It is estimated that an average reduction of 0.8 g/km in CO emission may be achieved for each 1.0% by volume of anhydrous ethanol blended with gasoline. This reduction has been estimated considering blends up to 25% by volume of ethanol. When comparing CO emission from vehicles fueled with neat ethanol and 20% gasohol, the ethanol fueled vehicles will emit 45% to 70% of the CO emitted by the 20% gasohol vehicle.

Particulate emission is also expected to be considerably reduced with ethanol use but, because very little data has been produced (10), definite conclusions shall not be drawn yet.

When referring to NOx and HC, there is still a great deal of controversy. NOx emission for the ethanol vehicles has been equal, higher or lower than for the 20% gasohol vehicles. This variability is explained by the different engine design and calibrations adopted by the manufacturers for fuel economy and performance improvements. HC emission, which is in fact a mixture of hydrocarbons, aldehydes, ketones, alcohols and other trace components, cannot be adequately compared when different fuels such as gasoline, 20% gasohol and ethanol are considered. Because HC emissions are measured by a flame ionization detector that gives a different response for ethanol, gasoline and ethanol/gasoline blends emissions, the data should not be compared unless further investigations indicate that they may be correlated in some way. The composition and quantity of these fuel derived emissions determine their toxicity and their role as oxidant precursors.

Evaporative emissions are the result of fuel evaporating from the vehicle fuel system and from fuel storage facilities. It has been reported that the use of alcohol/gasoline blends result in a significant increase in evaporative emissions when compared to gasoline or ethanol emissions. This increase is due to a chemical interaction between alcohol and gasoline molecules when mixed which results in blends having a greater tendency to evaporate than either alcohol or gasoline alone (10, 11). Again, the composition and quantity of these emissions determine their toxicity and their role as oxidant precursors.

Despite some air pollution benefits due to the ethanol and 20% gasohol use, vehicle related air pollution is still a very serious problem in many Brazilian urban areas. In São Paulo City, which has a population of about 10 million people, CO and O_3 ambient concentrations routinely exceed the air quality standards which are 9 ppm (8-hour average) and 82 ppb (1-hour average) respectively. Peak concentrations can be as high as 26.7 ppm (8-hour average) for CO and 226.0 ppb (1-hour average) for O_3. Although Brazil has not air quality standards for non Methane HC and NO_x, recorded peak concentrations for these pollutants in São Paulo City are 4 ppmC (7-9am average) and 509 ppb (annual average) respectively.

These air quality values were measured in 1981. For this year the contribution to air pollution by the 1,800,000 São Paulo City light duty vehicle fleet has been estimated as:

1,488,658 t(*)/year of CO
174,913 t(*)/year of HC
34,605 t(*)/year of NO_x

6,579 t(*)/year of SO_x

5,526 t(*)/year of Particulates

(*) Metric tons

Source: (12)

Ethanol vehicles correspond only to 4,6% of the above referred fleet.

Michael P. Walsh, a former U.S. Environmental Protection Agency Deputy Assistant Administrator, declared after his consulting works with CETESB:

"In the aggregate, when one considers carbon monoxide, photochemical smog, nitrogen dioxide, hydrocarbons and particulates, it seems clear that São Paulo has one of the most severe vehicle related air pollution problems in the world".

Although precise evaluation of the vehicle related air pollution in the other Brazilian urban areas is not possible because the air quality monitoring networks are not as comprehensive as in São Paulo, the air pollution is probably severe today in cities like Rio de Janeiro, Belo Horizonte, Recife, Salvador and Porto Alegre. If no action is taken to control vehicle emissions, many other areas will have to face high air pollution levels in the foreseeable future.

The average exhaust emission figures for Brazilian new light-duty vehicles are presented in Table 7 and are valid for models built from 1981 through 1983.

Table 7 - Average Exhaust Emission for Brazilian New Light-Duty Vehicles - g/km

Pollutant / Fuel	CO	HC(*)	NO_x	R-CHO(**)
Neat ethanol	17.6	1.5	1.1	0.18
20% gasohol	28.6	2.5	1.3	0.05

(*) HC as measured by a FID calibrated with propane

(**) R-CHO as measured with MBTH Method

Source: CETESB

The data show that the emission levels for the uncontrolled Brazilian vehicles are very high. In fact, CETESB has estimated that it will not be possible to reduce vehicle air pollution to desired levels in São Paulo City with the present emission situation. The adoption of modern emission control technologies that have been demonstrated to work well in countries where emission control is required, is the first step to cut down vehicle air pollution. Some of these technologies have been shown to be economically feasible and compatible with energy conservation programs and there is no acceptable reason to not enforce the adoption of these technologies soon.

CONCLUSION

Brazil has adopted ethanol as the main alternative to oil based fuels for Otto cycle engines. Despite the progress achieved in engine development for ethanol and ethanol/gasoline blends use, no important progress has been achieved in controlling air pollutant emissions. The result is that a number of highly populated urban areas still have to cope with severe vehicle generated air pollution. The situation can even get worse due to the considerable emission of alcohols, ketones, aldehydes and organic acids from the ethanol and gasohol fueled vehicles. The most practical way to cut down emissions from new vehicles rapidly is to adopt emission control technologies that have proven to be efficient elsewhere. This shall not present special difficulties for the Brazilian vehicle manufacturers like General Motors, Ford, Fiat and Volkswagen that have been developing these technologies for many years in their countries of origin or elsewhere. However, unless the Brazilian government sets up an emission control program and requires a sharp emission reduction, no manufacturer will adopt control technologies willingly.

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