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Emission Characteristics of Mexico City Vehicles

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The University of Denver remote sensor for automobile exhaust was set up for nine days at five locations in the Mexico City area. A total of 31,838 valid readings for CO and HC emissions were obtained. The emissions distribution was unlike any other we have observed in North America or Europe, in that the emissions for both CO and HC were vastly greater than seen elsewhere. The readings are discussed in terms of the fraction of CO and HC which would be measured by a tailpipe probe, and in terms of grams emitted per gallon of gasoline. The median CO emission was 3.8 percent, with half of the CO emissions coming from the 24 percent of the fleet with over 6.6 percent CO in the exhaust. The median HC emission was 1,100 parts per million measured as propane equivalent, while half the emissions come from twelve percent of the fleet with more than 4,000 ppm propane equivalent in the exhaust.

In order to determine the exhaust characteristics of the Mexico City vehicle fleet, a Fuel Efficiency Automotive Test (FEAT) unit was placed at five different sites over a 10-day period from February 11, 1991 through February 21, 1991. Valid data for the percent of carbon monoxide (CO), hydrocarbons (HC) and carbon dioxide (CO_2) were obtained on 31,838 vehicles. This represents approximately 1 percent of the entire Mexico City fleet.

The FEAT Unit

The FEAT unit consists of an infrared light source placed on one side of a single lane road with a receiver unit on the other side. The source and receiver may be placed on the same side of the road if a suitable mirror is placed on the other side. The receiver contains four lead selenide thermoelectrically cooled detectors which view the source through separate bandpass filters. Three of these filters isolate the CO, CO_2 and HC absorption bands at 4.6 μm, 4.3 μm and 3.3 μm, respectively. The fourth bandpass filter is at 3.9 μm, a spectral region in which these molecules do not absorb. The signal from this detector thereby serves as a reference.

The absorption seen in each of the first three wavelength channels is ratioed to the reference channel, eliminating the effect of dust and smoke behind the vehicle. These ratios are normalized to the background absorption obtained in front of the vehicle and are then compared to experimentally determined calibration curves for each of the gases to determine the path-integrated concentration of each gas. Since we cannot know what portion of the exhaust plume the infrared radiation passed through, we cannot directly determine the absolute amount of each gas in the plume. However, we can calculate the CO/CO_2 and HC/CO_2 ratios, and through the combustion equations, determine the CO, CO_2 and HC fractions present in the dry exhaust plume, as would be measured by a standard tailpipe exhaust monitor.[1-31]

The unit is calibrated daily with a certified gas mixture consisting of known percentages of CO, CO_2, propane (for HC) and nitrogen. The device is calibrated with propane, but other hydrocarbons may have different sensitivities at 3.3 micrometers. Therefore, we report all HC measurements as "propane equivalents," the fraction of propane which would give the same IR absorption as the emitted HC components. The instrument is approximately twice as sensitive to hexane as to propane, so we would measure a sample containing 1,000 ppm hexane as roughly 2,000 ppm propane equivalent.

The FEAT signals are digitized and acquired by a computer system. The unit uses an automatic data analysis routine which is triggered and attempts a measurement each time the infrared beam is blocked. If the noise on the measurement exceeds preset bounds,[2] the measurement is labeled invalid. Invalid measurements are also caused by failure to detect an exhaust plume, as occurs when the beam is blocked by pedestrians, bicycles and vehicles with high-mounted exhaust pipes. For this study, we have chosen to analyze only those triggers which resulted in valid measurements for all three of the gases.

A video camera is trained on the back of the cars as they pass the sensor, with a freeze-frame image of each vehicle stored on video tape. The tapes may then be reviewed, and the license plate number recorded for each vehicle measured. The license numbers may then be matched with motor vehicle records in order to determine the make, model and age of each vehicle and the average age of the fleet.

Implications

This article finds that motor vehicles in the Mexico City basin area emit high levels of carbon monoxide and hydrocarbons. This observation is expected from vehicles which do not have U.S. emission controls. However, there is an unexpectedly large number of gross polluters, such that the fleet average emission of CO exceeds that of a 15 year old pre-control U.S. fleet.

The results indicate that there is a need for improved maintenance of the Mexico City vehicles to control the gross polluters and tune the vehicles closer to stoichiometry. This procedure alone would reduce the pollutant emissions by nearly a factor of two. In addition, closed cycle emission control systems will result in a future improvement, but this will require proper maintenance of the fleet and prevention of misfueling.

Table I. The sites and times of operation and the number of vehicles registered by the FEAT unit.

Date (Feb. 1991)	Location[a]	Times of operation	Vehicles/triggers[b]
11[c]	IMP	1330–1430	359/431
12	IMP	0940–1600	2409/2831
13	IMP	0950–1550	2413/2836
14	POL	0830–1600	4090/4408
15	POL	0900–1530	3153/3446
16	POL	0910–1510	1921/2081
18	UAM	0840–1650	1971/2207
19	UAM	0830–1700	2055/2253
20	PER1	0820–1640	8922/9498
21	PER2	0845–1722	4904/5246
Total			31838/34806

[a] Locations:

IMP: North site, return lane at Eje Central Lazaro Cardenas northbound to southbound at the intersection with Av. Montevideo north of the Instituto Mexicano del Petróleo.

POL: West site, Eastbound L. G. Urbina at A. Dumas in Polanco.

UAM: East site, lane from southbound San Rafael St. into Westbound Gavilán St., in front of Universidad Autónoma Metropolitana, Iztapalapa.

PER1: South site, ramp from eastbound Periferico to northbound Tlalpan.

PER2: South site, ramp from westbound Periferico to southbound Tlalpan.

[b] Number of vehicles for which the CO, HC, and CO_2 measured were all valid, and the total number of attempted measurements. The latter include, in addition to the data rendered invalid by noise, triggers caused by bicycles, pedestrians, and setup.

[c] Unpacking and setup of the FEAT unit, with checkout and demonstration. No calibrations performed on this day, and the data are not included in any further analysis.

Validation

The measurements obtained from the FEAT unit have been shown to accurately reflect the instantaneous emissions of vehicles. Studies sponsored by the California Air Resources Board (CARB) in collaboration with General Motors (GM) Research Laboratories included tests of the instrument using a specially equipped GM vehicle. This vehicle had on-board controls which allowed varying the air-fuel ratio and so could produce a range of CO levels in the exhaust. In addition, the vehicle had an on-board exhaust gas analyzer monitoring the tailpipe emissions. In a double-blind test in which the vehicle operators randomly varied the engine operating parameters without informing the FEAT operators, there was excellent agreement between the on-board analyzer and the FEAT measurements.[4] In addition, the University of Denver FEAT unit shows excellent agreement with a remote sensor designed by General Motors Research Laboratories.[5] More recent tests by the CARB for both CO and HC also show that the FEAT CO measurements are within ±5 percent of the values reported by the on-board gas analyzer, and within ±15 percent for HC.[6]

Discussion

The sites we monitored are listed in Table I. These sites were chosen with the assistance of personnel from the Instituto Mexicano del Petróleo (IMP). They were chosen to have a good traffic flow cruising at about 20 miles/hour, and to represent different regions of Mexico City with corresponding different fleet profiles. This information, in combination with the video tapes and license plate registry, should allow extrapolation to the true fleet profile of Mexico City. In addition, it was necessary to choose locations where the traffic flow was essentially confined to one lane. Table I includes the date, location, times of operation and number of vehicles registered on each day of operation. The total number of triggers was 34,806. Of these, there were 31,838 measurements (91 percent) for which the CO, HC and CO_2 all measured valid. If we were unable to properly measure any one of the gases, we considered the entire measurement invalid. In addition to the data rendered invalid by excessive noise, triggers caused by bicycles, pedestrians and setup and alignment are included in the 9 percent of

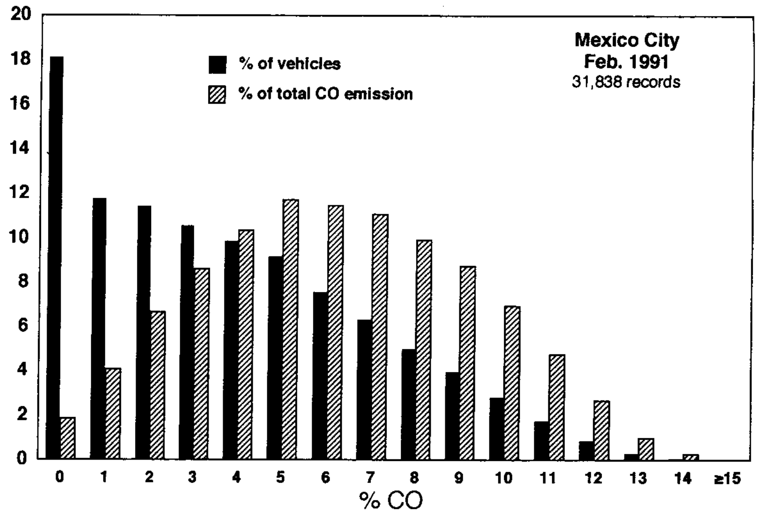

Figure 1. The fraction of vehicles and their fractional CO contribution for the Mexico City fleet. The solid bars represent the fraction of the total number of vehicles in each measured category (i.e., 0 is for vehicles measured as 0 to 1 percent CO). The hatched bars represent the fraction of the total emissions contributed by the vehicles in each category.

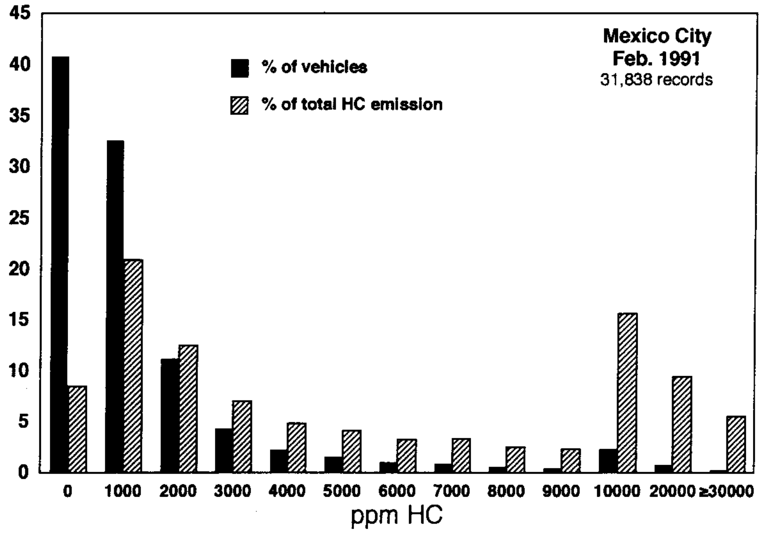

Figure 2. The fraction of vehicles and their fractional HC contribution for the Mexico City fleet. The solid bars represent the fraction of the total number of vehicles in each measured category (i.e., 0 is for vehicles measured as 0 to 1,000 ppm HC). The hatched bars represent the fraction of the total emissions contributed by the vehicles in each category.

invalid attempted measurements. The first day, February 11, was devoted to checkout and demonstration of the unit and no calibrations were performed. Since we have no calibration data for this day, we have not included these measurements in any further analysis.

We have calculated the vehicle emissions both in terms of grams per U.S. gallon of gasoline (g/gal) and as a percent of the dry exhaust volume.[2] These are both calculated directly from the measured emission ratios and the appropriate form of the combustion equations. The g/gal value is more appropriate for determining the inventory of each species emitted into the Mexico City air basin, since the quantity of gasoline sold can be determined. This inventory analysis assumes that the average g/gal emissions can be multiplied by the total number of gallons sold to apply to the entire fleet. We believe this is valid for the large number of vehicles studied. Note that g/gal values are derived directly from the remote sensing measurements and are not dependent on individual vehicle gas mileage. Vehicle gas mileage is only necessary should one wish to derive gram/mile estimates. The percentage values allow comparison to vehicle emission standards and to previous studies we have performed in the United States and elsewhere. The g/gal and percentage values were calculated from the measured emission ratios for each individual vehicle, before calculating fleet values such as the average and median.

For the purposes of hydrocarbon exhaust emissions inventory we suggest multiplying the g/gal HC value by U.S. gallons sold in the Mexico City basin, and treating the number so generated as mass of total hydrocarbons. Since exhaust emissions are not all propane, in order to model the ozone formation potential, the total hydrocarbon mass calculated by this method should be apportioned by means of the mass fractions obtained in other studies.

Carbon Monoxide Emissions

The average for the 31,838 vehicles with all valid measurements was 4.3 percent by volume, or 1330 g/gal of CO. The average emission is dominated by the high emitters, so that the median of the fleet is slightly lower than the average, at 3.8 percent (1,260 g/gal) of CO. If the number of vehicles in a given CO range is multiplied by the average emission for that range, the fraction of the total emissions due to each range is obtained, as is shown in Figure 1. For this histogram, the fraction of cars in each 1 percent (200 g/gal) CO bin is determined, and the fraction of the total CO emission due to each bin is calculated. Clearly, the small number of cars with high emissions are contributing a disproportionate share of the total CO emitted into the Mexico City basin, as we have observed elsewhere.[2–4,7,8] But our Mexico City observations show that the highest emitting 25 percent of the fleet contributes 50 percent of the total emissions, as compared with remote sensing measurements from the U.S., where only 10 percent of the fleet is responsible for approximately 50 percent of the total CO emitted. The average emission of this 25 percent is 8.8 percent (2,530 g/gal) CO, with the lowest emission at nearly 6.6 percent (2,000 g/gal) CO. The lower value, which marks the lowest emission value of the vehicles responsible for 50 percent of the total emitted pollutants, we call the gross polluter cut-point. The removal or repair of these gross polluters would nearly halve the amount of carbon monoxide entering the atmosphere from vehicles. Repair of the gross polluters which are also driven many miles, such as taxis and delivery vehicles, would result in an even larger improvement.

Hydrocarbon Emissions

The percentage of hydrocarbons in the exhaust and the grams HC per gallon of fuel were also determined, and are reported in propane equivalents. The average for the fleet is 2,100 ppm HC, or about 96 g/gal. As with CO, the distribution is skewed, with a median of only 1,100 ppm (60 g/gal) HC. For HC, the gross polluters, those vehicles contributing 50 percent of the total emissions, were only 12 percent of all vehicles. The cutoff point was at 4,000 ppm (150 g/gal) HC, and the mean for these gross polluters was

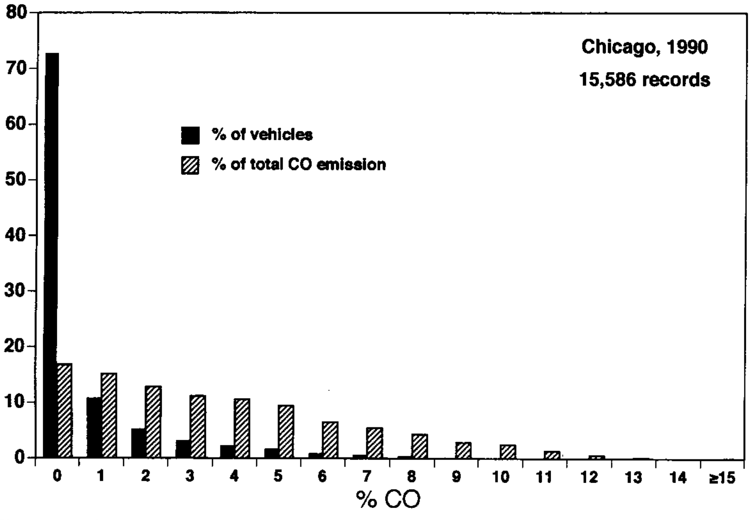

Figure 3. Observed vehicle numbers and their fractional CO contribution for a typical U.S. fleet.

Table II. Comparison of the Mexico City fleet to typical U.S. fleets. Pre-75 refers to vehicles in Los Angeles whose model year is prior to 1975, which are pre-catalyst vehicles. Hydrocarbon measurements are in propane equivalents, as discussed in the text.

	Percent CO			
	Average	Median	% Gross poll.[a]	Gross cutpoint[b]
Mexico City	4.3	3.8	26	6.6
Chicago[3]	1.1	0.4	9.4	3.5
Denver[7]	1.0	NA	7–10	NA
Los Angeles[8]	1.6	0.4	11	5.0
Pre-75	3.6	2.8	21	6.2
			ppm HC	
Mexico City	2100	1100	14	4000
Chicago[3]	1400	870	14	2300

[a] The % gross polluters is that percentage of the fleet which contributes 50% of the total fleet emissions.

[b] The gross cutpoint is the lowest emission value which identifies the gross polluters.

about 10,000 ppm (350 g/gal) HC. The HC histogram is shown in Figure 2. Note the scale change at the high end, where the last three bins have a width of 10,000 ppm, while the width of the lower bins is 1,000 ppm.

The vehicles which are emitting over 10,000 ppm HC, and particularly those which are emitting over 20,000 ppm HC, almost certainly have at least one cylinder misfiring, and their potential for saving money by improved gas mileage is large. Furthermore, those vehicles alone are responsible for 30 percent of the HC even though they constitute less than 4 percent of the fleet. In the highest bin, a mere 107 vehicles out of 31,838 (0.3 percent of the fleet) are alone responsible for 5.6 percent of the total HC emitted.

Comparison with Other Fleets

Figure 3 shows the %CO histogram for a typical U.S. fleet.[3] This can be compared with the Mexico City data in Figure 1. The typical U.S. fleet has an average CO emission of about 1 percent, with a median of less than 0.4 percent. It is apparent that the U.S. fleet distribution is much lower emitting and more skewed than the Mexico City distribution. In the U.S., 50 percent of the total fleet emission arises from only about 10 percent of the vehicles, with a gross polluter cutpoint around 5 percent CO. The U.S. cutpoint is only slightly different from the Mexico City cutpoint, but the percentage of vehicles below the cutpoint is much lower in Mexico City.

The observed higher emissions in Mexico City are caused by a combination of two factors: the lack of adequate maintenance (as we have observed in the U.S.)[4] and the lack of emissions control equipment. Improving the fleet maintenance will immediately reduce the fleet average emissions. We have found in Los Angeles that 1975 and older pre-control U.S. vehicles have lower average CO emissions than the Mexico City fleet.

The introduction of closed-loop, catalytic converter-equipped cars will also result in large reductions in the average fleet emission, but this requires the proper fuel and upkeep to maintain the control system effectiveness. Also, it will take a number of years before the fully controlled vehicles constitute the majority of vehicles in Mexico City.

Table II summarizes the comparison between the Mexico City fleet and some other fleets which we have measured. The Los Angeles data have also been broken down to vehicles built prior to the 1975 model year. Perhaps the most striking analysis of the differences between the CO emissions in Mexico City and elsewhere is shown in Figure 4. Each point in the Figure corresponds to a random grouping of 100 U.S. vehicles. Also shown are the results of measurements in the U.K. in November 1990, Toronto in April 1990 and the Mexico City data. Since the average age of the Mexico City fleet which we observed is not known, we have estimated an average age between 6.5 and 10 years, as shown by the length of the box. In comparison to other fleets of similar age, of which most vehicles have emission control equipment, the Mexico City fleet has much higher CO emissions. The U.K., where catalytic converters are only recently being introduced, also has much lower emissions than the Mexico City fleet. Since we do not yet know the actual age of the Mexico City fleet, it is difficult to determine if the U.K. fleet has lower emissions after adjusting for differences in fleet average age.

Our data indicate that a large fraction of the on-road fleet are operating in the 3–6 percent CO category. This is close to the correct tuning for a vehicle for which peak power is the most important parameter. It appears that many Mexico City vehicles are deliberately tuned to this level. If this is the case, and the tune-up industry could be persuaded to tune vehicles to an

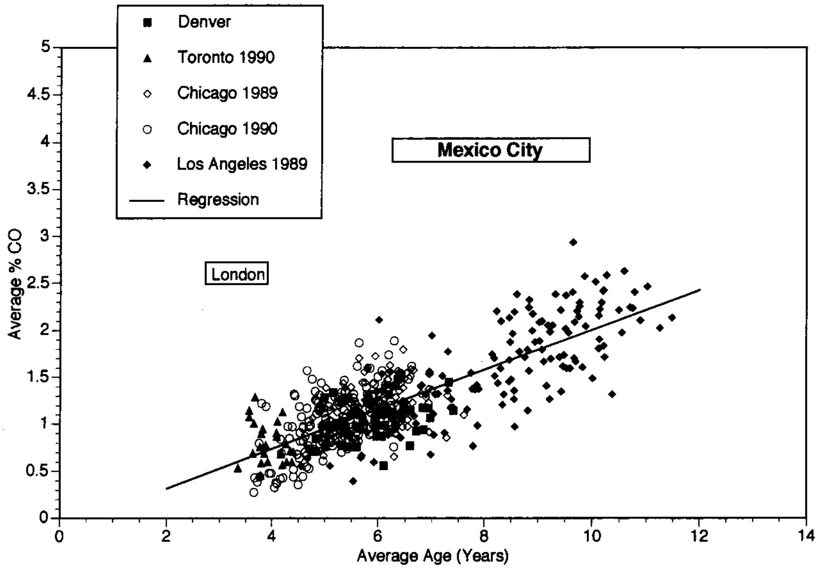

Figure 4. The correlation between %CO emissions and fleet age for 49,700 vehicles. Each data point represents the average of 100 vehicles. The average age of the Mexico City fleet is estimated to be 6–10 years. The oldest Los Angeles data are from the Lynwood area, the remainder are from the Westchester and Los Alamitos areas.

Table III. The daily averages for CO and HC emissions and the hourly traffic flow past the FEAT unit.

Site	Date Feb. 1991	CO g/gal	CO %	HC g/gal	HC ppm	Hourly rate vehicles/hour
IMP	12	1619	5.4	133	3000	380
	13	1666	5.6	166	3800	402
POL	14	1476	4.8	97	2200	545
	15	1529	5.0	107	2500	485
	16	1476	4.8	112	2600	320
UAM	18	1289	4.1	85	1900	241
	19	1304	4.2	91	2000	241
PER1	20	1035	3.2	63	1300	1070
PER2	21	1288	4.1	99	2100	565
Overall[a]		1331	4.3	96	2140	

[a] Overall refers to the overall average emission weighted by the number of vehicles at each site.

average of only 2 percent CO instead of 5 percent CO, the overall emissions of CO (and probably HC) would be reduced by as much as a factor of two, with existing emission control equipment. Comparison to the older, pre-1975 fleet in Los Angeles, where maintenance is emphasized, indicates the gains that are possible.

Daily Analysis

Table III gives the average emissions in each category for each of the days worked, as well as the average hourly vehicle rate. In previous studies we have found that the site-to-site differences are usually directly related to the average age of the vehicles at each site. The fleet profiles given in Figures 1 and 2 closely describe the daily fleet profiles, although the IMP site had slightly fewer cars in the lowest emission category. This is reflected in the slightly higher emission averages found for the IMP site.

The hourly traffic volume at any given site is nearly constant, except for the third day at the POL site (February 16), which was a Saturday. All other measurements were taken on weekdays. Even though the Saturday traffic rate was less than two-thirds that recorded on the preceding two weekdays, the emissions are virtually unchanged. The PER2 site was at an off/on ramp diagonally opposite the PER1 site. The very high traffic flow at the PER1 site caused extensive backups on the ramp, and for safety reasons we chose to move to the other, less busy ramp designated PER2. Although the traffic was often backed up at the PER1 site, this does not affect the reliability of the data. The backups occurred upstream of the sensor, where the traffic was being forced into a narrower lane. The traffic flow past the sensor was constant, and had returned to moderate speeds.

The data in Table III indicate that there is no discernible correlation between the hourly vehicle rate and the average CO emission recorded for each day. This shows that the FEAT instrument is insensitive to the vehicle rate, provided there is more than one second (the FEAT measurement period) between vehicles. Therefore, the differences in fleet averages are true differences, and not an artifact of the traffic flow. Also apparent in Table III are the differences between each site as well as the similarities for different days at the same site.

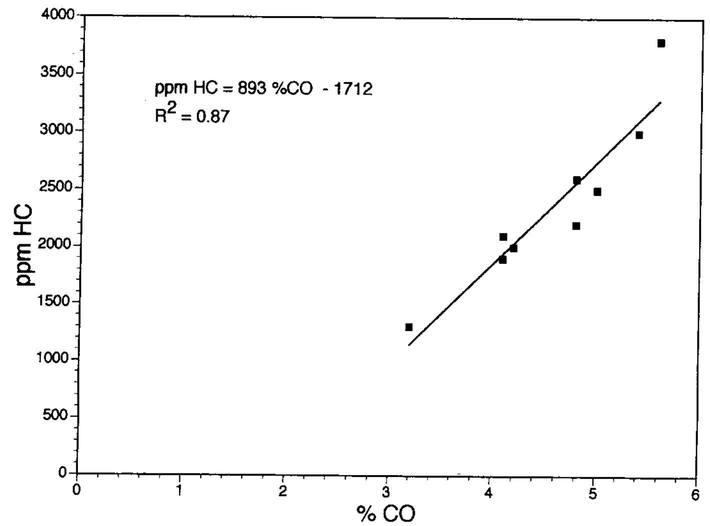

Figure 5. The correlation between the daily average HC emission and the daily average CO emission at Mexico City.

The daily averages of ppm HC are plotted against the daily averages of %CO, in Figure 5, showing the correlation ($R^2 = 0.87$) between the average %HC emission and the average %CO emission. This implies that the average %HC emission could be reasonably well predicted by determining the average %CO emission in a given region. This result simply implies that a region with high %CO emissions is a region with a large number of poorly maintained vehicles. From such a population, one can expect to also find a large number of high HC emitters.

Although on average, high CO emissions indicate high HC emissions, an individual vehicle emitting a large amount of CO is not necessarily a high HC emitter. This can be seen in Figure 6, where 3,500 individual vehicles are plotted. These data are roughly every tenth vehicle in the entire Mexico City database. There are some vehicles emitting copious amounts of HC with very little attendant CO. These vehicles most likely suffer from lean misfire, where the mixture has too little fuel to ignite. For rich air/fuel mixtures, the %CO increases as combustion becomes less complete, and more unburned fuel passes through the cylinders. If there is a partially functional converter, as are present on some newer vehicles, it will convert the fuel which was not burned in the cylinder into CO, resulting in very high CO values and low HC values. A fully functional emissions system with air addition would also oxidize the CO to CO_2, resulting in a low emitting vehicle. A very rich mixture combined with an ineffective or no catalytic converter will result in both high %CO and high %HC. This result is also possible with a poorly maintained vehicle where, for instance, one cylinder may be misfiring due to ignition problems while the other cylinders are running rich.

Conclusions

Motor vehicle emissions in Mexico City are unlike those we have seen in the rest of North America in that the average emissions are higher and there are more gross polluters. Proper maintenance alone would achieve a substantial reduction in emissions, as would modern catalytic converters. The change-over to converters, however, will take a long time, cost a considerable amount of money and require proper fuel and maintenance.

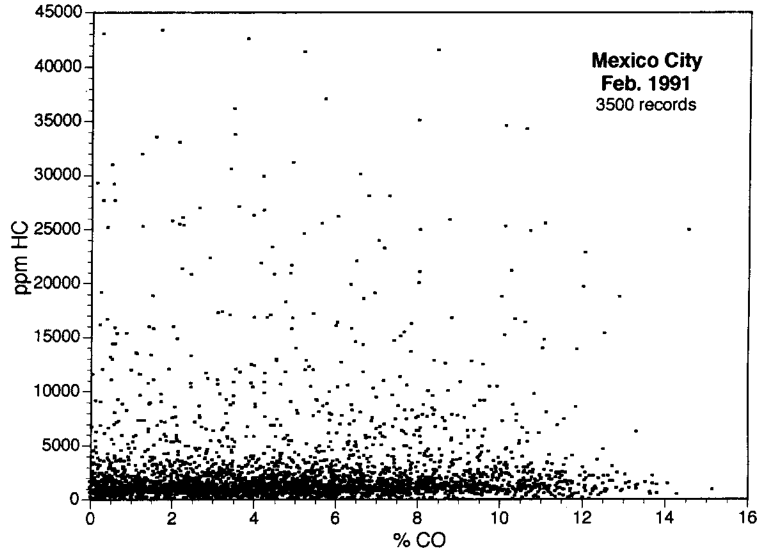

Figure 6. A correlation showing that, in contrast to fleet average data, individual vehicle HC emissions and CO emissions show considerable scatter. Illustrated are 3,500 vehicles from the Mexico City fleet. The data plotted are every tenth vehicle in the database.

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