LA-SUB--93-194

REPORT TO

LOS ALAMOS NATIONAL LABORATORIES

CONCERNING

AUTOMOBILE EMISSIONS IN MEXICO CITY

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AUG 14 1991

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SUMMARY

The University of Denver remote sensor for automobile exhaust was set up at various 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 observed in North America or in the United Kingdom, in that the emissions for both CO and HC were vastly greater than any we have seen elsewhere. The readings are discussed in units of both %CO and %HC which would be measured by a tailpipe probe, and grams emitted per gallon of gasoline. For HC half the emissions come from less than fifteen percent of the fleet with more than 8,000 ppm propane equivalent in the exhaust.

It is our opinion that emissions could be dramatically decreased and gas mileage dramatically improved by persuading the automobile mechanics to tune for better gas mileage.

INTRODUCTION

In order to determine the exhaust characteristics of the Mexico City vehicle fleet, a Fuel Efficiency Automotive Test (FEAT) unit was placed at 5 different sites over a 10 day period from 11 February 1991 through 21 February 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 % of the entire Mexico City fleet.

Background

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 receiver contains four lead selenide thermo-electric cooled detectors which view the source through separate bandpass filters. Three of these filters isolate the CO, CO_2, and HC absorption bands. The fourth filter isolates a spectral region in which these molecules do not absorb, thereby serving as a reference channel.

The unit is calibrated daily with a gas mixture consisting of known percentages of CO, CO_2, propane (for HC), and nitrogen. A full description of the original unit, which did not incorporate an HC sensor, is given in appendix 1. The HC sensor in the unit used for this study functions in a manner similar to the CO sensor described in the appendix. The sensor measures IR absorption at 3.3 micrometers as its hydrocarbon channel. The device is calibrated with propane, but all hydrocarbons have different sensitivities at 3.3 micrometers. Therefore, we report all HC measurements as "propane equivalents", namely the percentage of propane which would give the same IR absorption as the emitted HC components.

DISCUSSION

The sites we monitored are listed in Table 1. 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 and to represent different regions of Mexico City with corresponding different fleet profiles. This information, in combination with the 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 of traffic. Table 1 includes the date, location, times of operation, and number of vehicles registered on each day.

We have calculated the vehicle emissions both in terms of grams per gallon of gasoline (g/gal) and as a percent of the dry exhaust volume. These are both calculated from the combustion chemistry equations and the measured ratio of CO (or HC) to CO_2. The g/gal value is perhaps more appropriate for determining the quantity of each species emitted into the Mexico City basin, while the percentage values allow comparison to vehicle emission standards and to previous studies we have performed in the United States. The conversion factor from g/gal to percent by volume is non-linear. For this reason, the g/gal and percent values were calculated for each vehicle, before calculating values such as the average and median. The g/gal values can be converted to g/mile or g/km by dividing by the gas mileage (in miles/gallon or km/gal, respectively) of the vehicles. Appendix 2 gives this conversion for a range of values. For example, a vehicle emitting 200 g/gal of CO and getting 20 miles/gal will be emitting 10 g/mile CO.

CO emissions

The average for the 31 838 vehicles with all valid measurements was 1330 g/gal (4.3%) of CO. The average emission is slightly dominated by the high emitters, so that the median of the fleet is 1260 g/gal (3.8 %) of CO. If the number of vehicles in a given CO category are multiplied by the average emission for that category, the fraction of the total emissions due to each category is obtained, as is shown in Figure 1. For this histogram, the fraction of cars in each 250 g/gal (~1%) 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 percent of the total CO emitted into the atmosphere. We have determined that the 26% of the fleet with the highest emissions contributes 50% of the total emissions. The mean emission of this 26% is 2250 g/gal (~8.8%) CO, with the low-end cutoff point at nearly 2000 g/gal (6.6%) CO. Thus, the removal or cleanup of these gross polluters would nearly halve the amount of carbon monoxide entering the atmosphere from vehicles. Cleanup of those vehicles which are not only dirty but are also driven many miles, such as taxis, would make an even larger improvement than these numbers suggest. Figure 2 is the same data as in Figure 1 but in terms of percent CO. The slight differences between Figures 1 and 2 are due to the non-linearity of the conversion from g/gal to percent values, and the slightly different bin cutoff points.

For comparison, a typical American fleet will have an average CO emission of 1.5%, with a median of less than 0.4%. The equivalent histogram which results is shown in Figure 3. In this case, 50% of the total fleet emission arises from about 10% of the vehicles, with a cutoff point around 5%. Many of the clean vehicles in such a fleet have catalytic converters installed, though some of these clean vehicles have little or no emissions control equipment. This is also reflected in the Mexico City data, where catalytic converter equipped cars are still comparatively rare, but there is still a high percentage of clean-running vehicles.

If a vehicle is emitting less than 1% CO then the air to fuel ratio is either close to stoichiometric or lean. For a precontrol vehicle it is possible to operate just rich of stoichiometric and emit relatively little CO, HC and NO_x. If the mixture is lean, high NO_x emissions result. We have proposed the development of an NO channel for our remote sensor to a number of agencies, but funding has yet to be provided. Such a channel would provide direct answers about on-road NO emissions.

HC Emissions

The percentage and g/gal of HC were also determined, and are reported in propane equivalents, as discussed earlier. The average for the fleet is 96 g/gal, or about 0.213 percent HC. As with CO, the distribution is again skewed, with the median of only 60 g/gal (0.11 %) HC. For HC the gross polluters, those vehicles contributing 50% of the total emissions, was only 14% of all vehicles. The cutoff point was at 150 g/gal (~0.4 %) HC, and the mean for this 14% of vehicles was 350 g/gal (~1 %) HC. This is shown in the histogram in figure 4. Note the scale change at the high end, where the bins have a width of 1%, while the width of the lower bins is 0.1%. In the last bin, a mere 106 vehicles out of 31838 (0.3 percent of the fleet) is alone responsible for 5.5 percent of the total HC emitted.

Table 2 summarizes the comparison between the measured Mexico City fleet and some typical US fleets. Percent CO comparisons are available from studies done in Los Angeles and Chicago, while percent HC values for US fleets are only recently available from our work in Denver. The Los Angeles data has also been broken down to vehicles prior to the 1974 model year before emissions controls were introduced on a significant fraction of US automobiles. Even this old (minimum age of 15 years), pre-control fleet was measured to be cleaner than the Mexico City fleet.

Daily analysis

Table 3 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 4 closely describe the daily fleet profiles, although the IMP site had a smaller percentage of cars in the cleanest category. The hourly traffic volume at any given site is nearly constant, except for the third day at the POL site, which was a Saturday. All other measurements were taken on weekdays. 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 often backed up at the PER1 site (also at the PER2 site, though less severely), this will 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 and accellerations.

Perhaps the most striking analysis of the differences between the CO emissions in Mexico City and elsewhere in the USA is shown in Figure 5. In this figure, 35 000 vehicles measured in the US are shown as the points scattered about the line. Also shown are the results of measurements in the UK in November, 1990, and the Mexico City data. Since the average age of the fleet is not known, we have estimated a value between six and twelve years. When the video tapes have been read and the license plate data analyzed then the average age can be correctly determined, as well as the dependence of emissions on average age.

The shape of the percent CO distribution curve shows a large fraction of the on-road fleet are operating in the 3-6 %CO category. This is the correct tuning for a racing vehicle for which peak power is the most important parameter. If the tune-up industry could be persuaded to tune vehicles to an average of only 2 %CO instead of 5 %CO, the overall emissions of CO (and probably HC) would be reduced by as much as a factor of two. Comparison to the older, pre-1974 fleet in Los Angeles (Table 2 and Figure 6) where maintenance in emphasized indicates the gains that are possible. The vehicles which are emitting over one percent HC, and particularly those which are emitting over two percent HC almost certainly have at least one cylinder misfiring. Their potential for saving money by improved gas mileage is large, further those vehicles alone are responsible for 35% of the HC even though they constitute less than five percent of the fleet.

For the purposes of exhaust emissions inventory we suggest multiplication of the g/gal HC number by (US) gallons sold, 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 mass calculated by this method should be apportioned by means of the mass fractions obtained in other studies of pre-control automobile exhaust emissions.

Future studies with the remote sensor will develop better algorithms for this conversion, although the nature of a single channel NDIR is such that some assumptions of relative composition will always be required. Even if a perfect carbon counter were developed reactivity specification would be required. NDIR is by no means a perfect carbon counter.

Caveat

The calibration factors were determined based upon the *Certificado de Analisis* included with the calibration gas cylinder, ordered from *Linde de Mexico, S.A. de C.V.* The *Certificado* states that the proportions of gases was 0.60 % mol propane, 6.0 % mol CO, 6.0 % mol CO_2, and the balance nitrogen, as ordered. If these percentages are not accurate, then the calibration factors, and hence the stated emission quantities, will change accordingly. The distribution will remain constant, but with different cutoff values.

ACKNOWLEDGMENTS

We would like to thank the personnel of IMP and DDF, without whose assistance this project would have been much more difficult and our stay in Mexico City less enjoyable. We also would like to thank Jerry Streit of Los Alamos National Laboratory for his assistance and helpful comments.

Table 1. The sites and times of operation and the number of vehicles registered by the FEAT unit.

Date	Location[1]	Times	Vehicles/Triggers[2]
11 Feb	IMP	1330-1430[3]	359/431
12 Feb	IMP	0940-1600	2409/2835
13 Feb	IMP	0950-1550	2413/2839
14 Feb	POL	0830-1600	4090/4412
15 Feb	POL	0900-1530	3153/3450
16 Feb	POL	0910-1510	1921/2083
18 Feb	UAM	0840-1650	1971/2209
19 Feb	UAM	0830-1700	2055/2255
20 Feb	PER1	0820-1640	8922/9500
21 Feb	PER2	0845-1722	4903/5248
		TOTAL	31838/34806

[1] Locations:

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

POL: West site, intersection of L. G. Urbina and A. Dumas in Polanco.

UAM East site, ramp at Universidad Autónoma Metropolitana

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

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

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

[3] Unpacking and setup of the FEAT unit, with checkout and demonstration. No calibrations performed.

Table 2. Comparison of the Mexico City fleet to typical US fleets. Pre-74 refers to vehicles in Los Angeles whose model year is 1974 or earlier, which are pre-emission control vehicles.

Percent CO

	Mexico City	Los Angeles	LA Pre-74	Chicago
Average	4.3	1.6	3.6	1.2
Median	3.8	0.4	2.8	0.2
% gross poll.[1]	26	11	21	8.2
gross cutpoint[2]	6.6	5.0	6.2	4.5

Percent HC

	Mexico City	Denver
Average	0.21	0.06
Median	0.11	0.04
% gross poll.[1]	14	14
gross cutpoint[2]	0.4	0.1

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

[2] The gross cutpoint is the lowest emission value which identifies the gross polluters as defined above.

Table 3. The daily averages for CO and HC emissions and the hourly traffic flow past the FEAT unit.

Site	Date	CO_f g/gal	CO %	HC g/gal	HC %	hourly rate Vehicles/hour
IMP	12 Feb	1619	5.4	133	0.30	380
	13 Feb	1666	5.6	166	0.38	402
POL	14 Feb	1476	4.8	97	0.22	545
	15 Feb	1529	5.0	107	0.25	485
	16 Feb	1476	4.8	112	0.26	320
UAM	18 Feb	1289	4.1	85	0.19	241
	19 Feb	1304	4.2	91	0.20	241
PER1	20 Feb	1035	3.2	63	0.13	1070
PER2	21 Feb	1288	4.1	99	0.21	565
Overall[1]		1331	4.3	96	0.21	

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

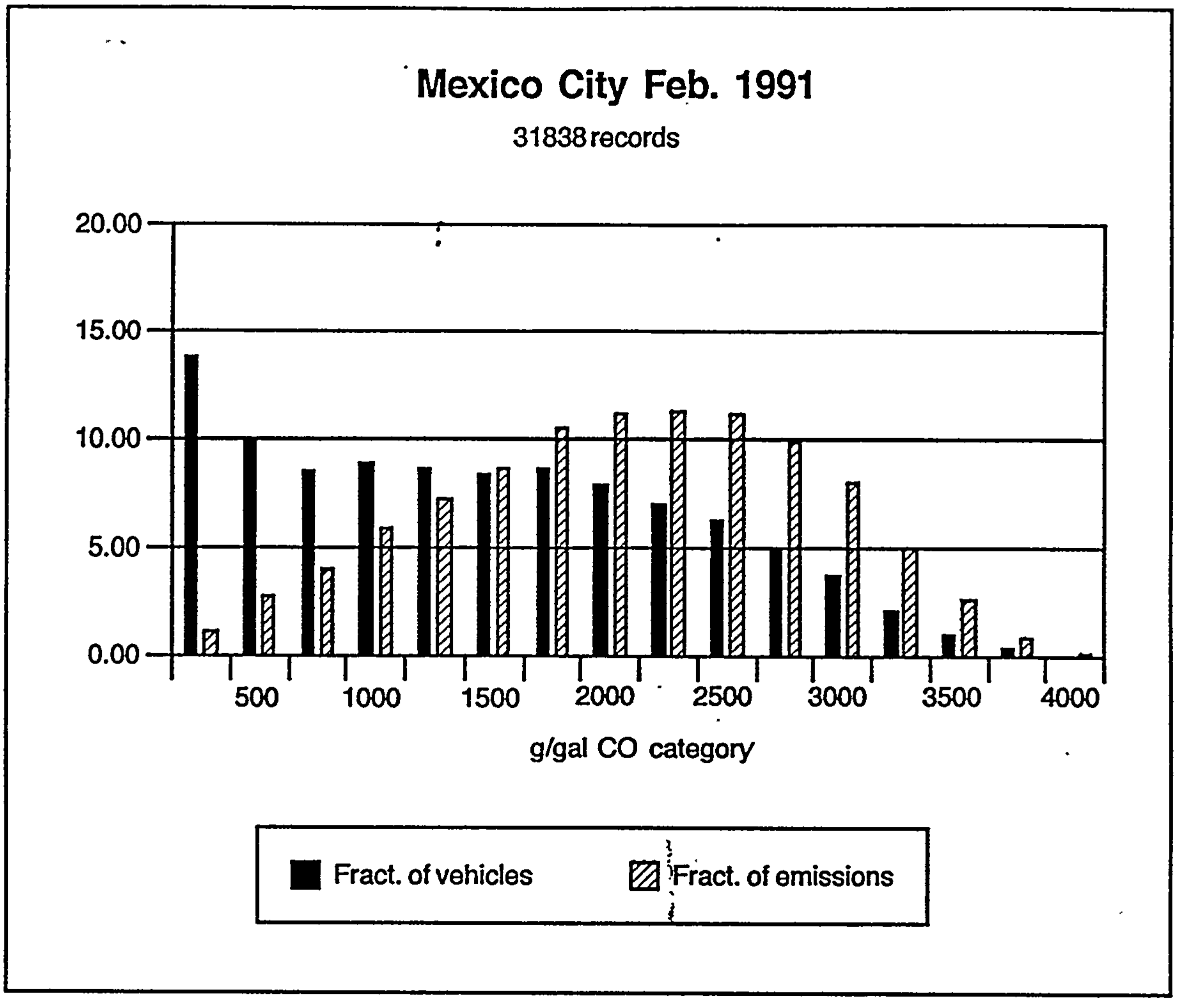

Figure 1. Normalized vehicle numbers and their fractional CO contribution for the Mexico City fleet. The solid bars represent the fraction of the total number of vehicles in each measured category (i,.e. 250 is for vehicles measured from 0 to 250 g/gal CO). The hatched bars represent the fraction of the total emissions contributed by the vehicles in each category.

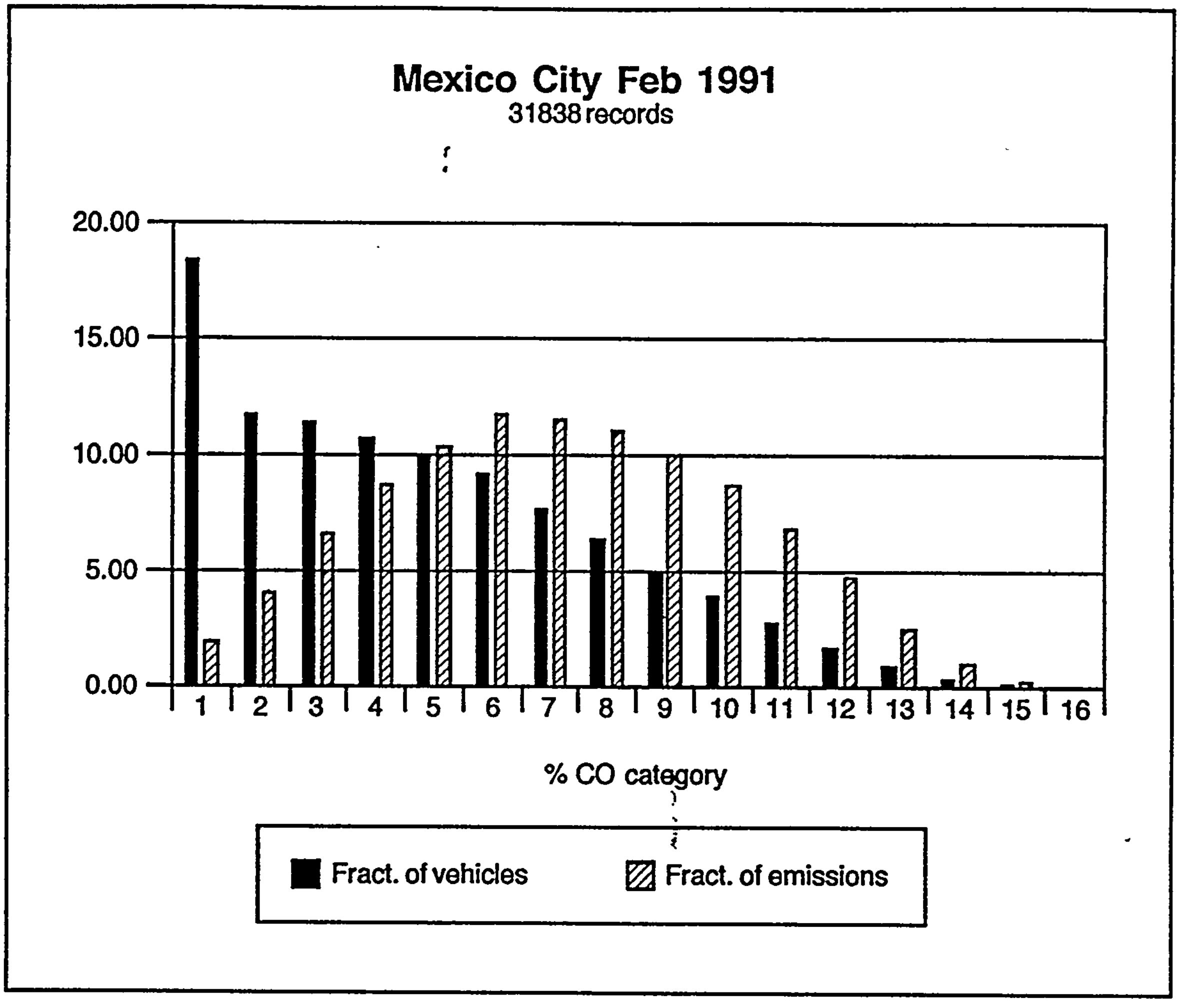

Figure 2. The Mexico City data as in Figure 1, but in terms of % CO. The apparent differences result from the non-linear conversion from g/gal to % CO and different category sizes.

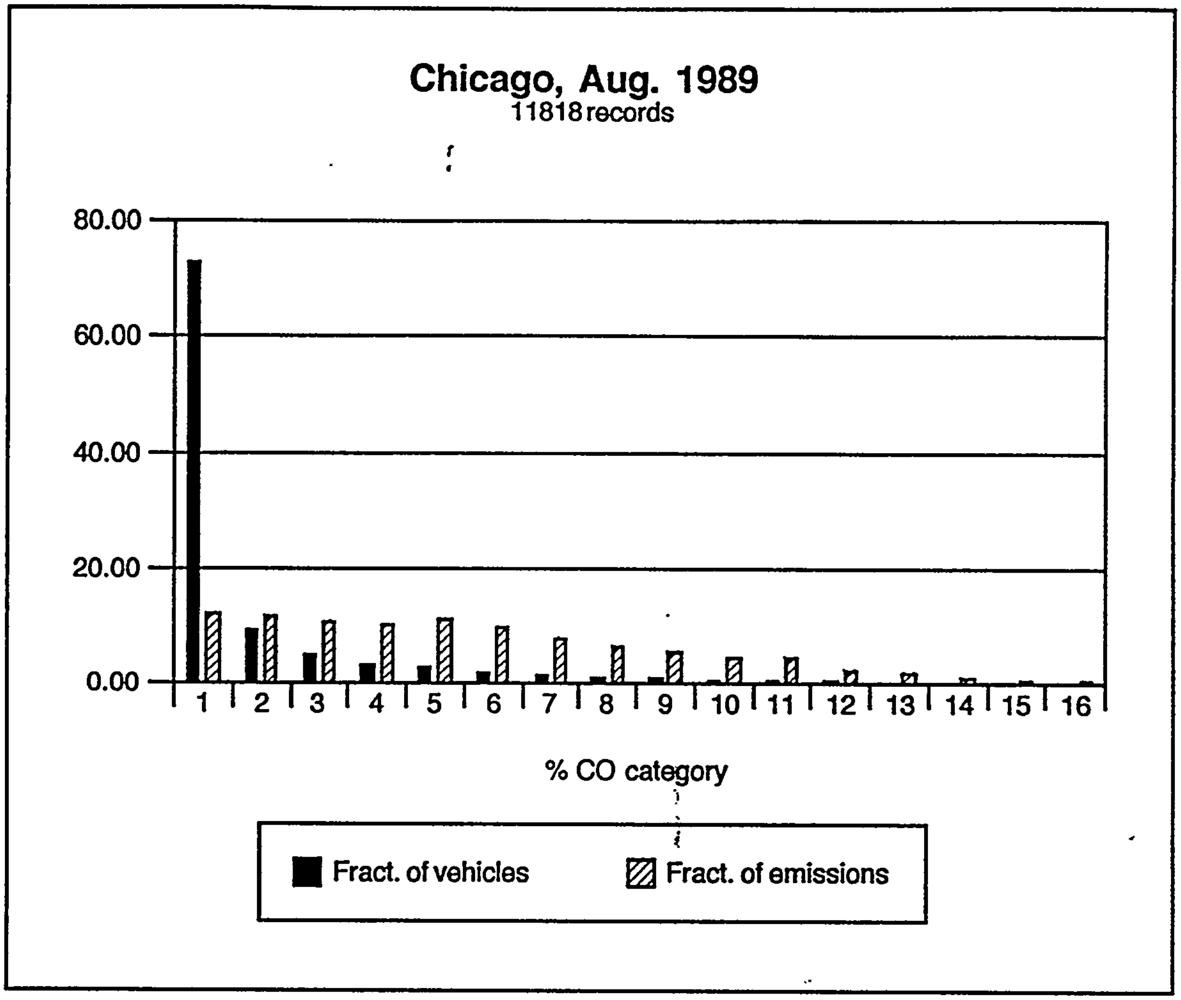

Figure 3. Observed vehicle numbers and their fractional CO contribution for a typical US fleet.

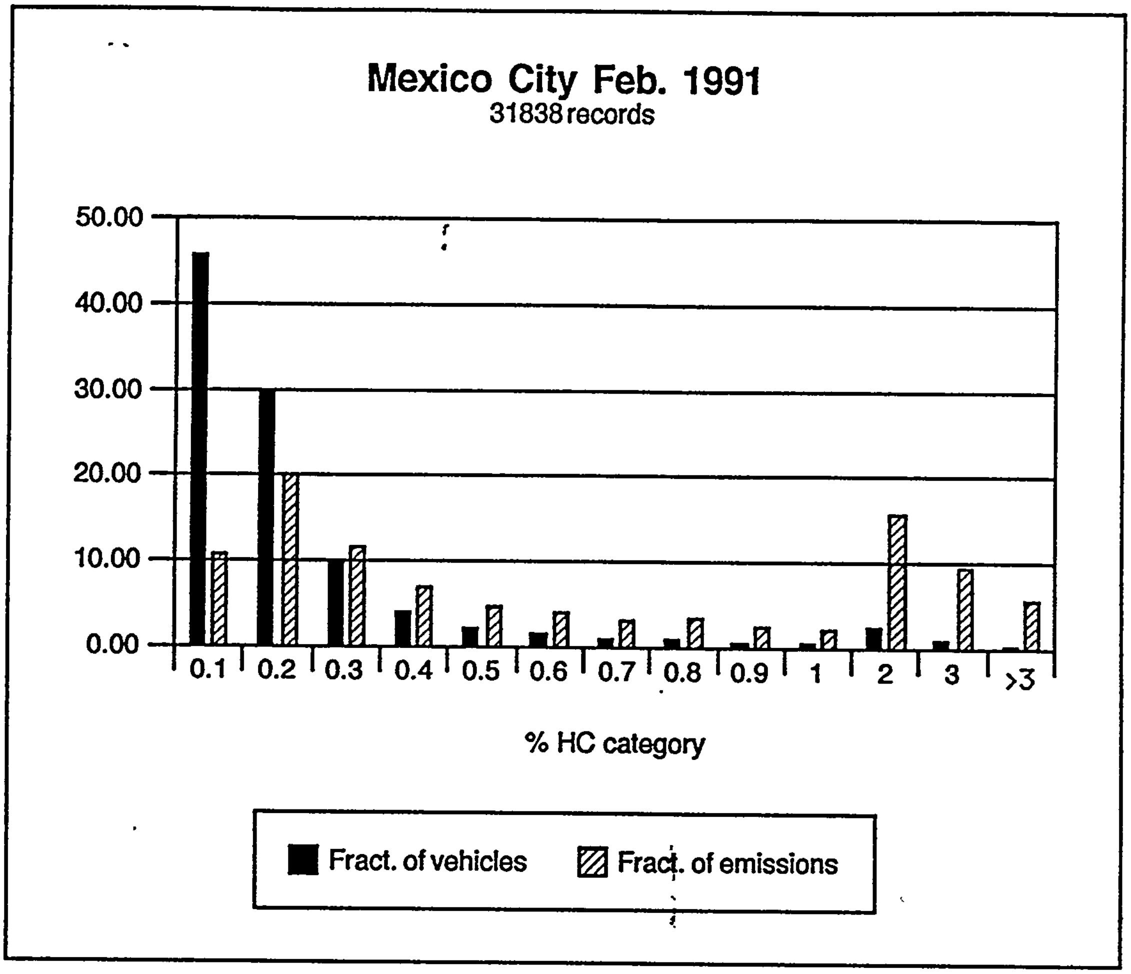

Figure 4. Normalized vehicle numbers and their fractional HC contributions to the Mexico City fleet. The solid bars represent the fraction of the total number of vehicles in each measured category (i.e. 0.1 % is for vehicles measured from 0 to 0.1 % HC). The hatched bars represent the fraction of the total emissions contributed by the vehicles in each category. Note the change of scale for the right-most three categories.

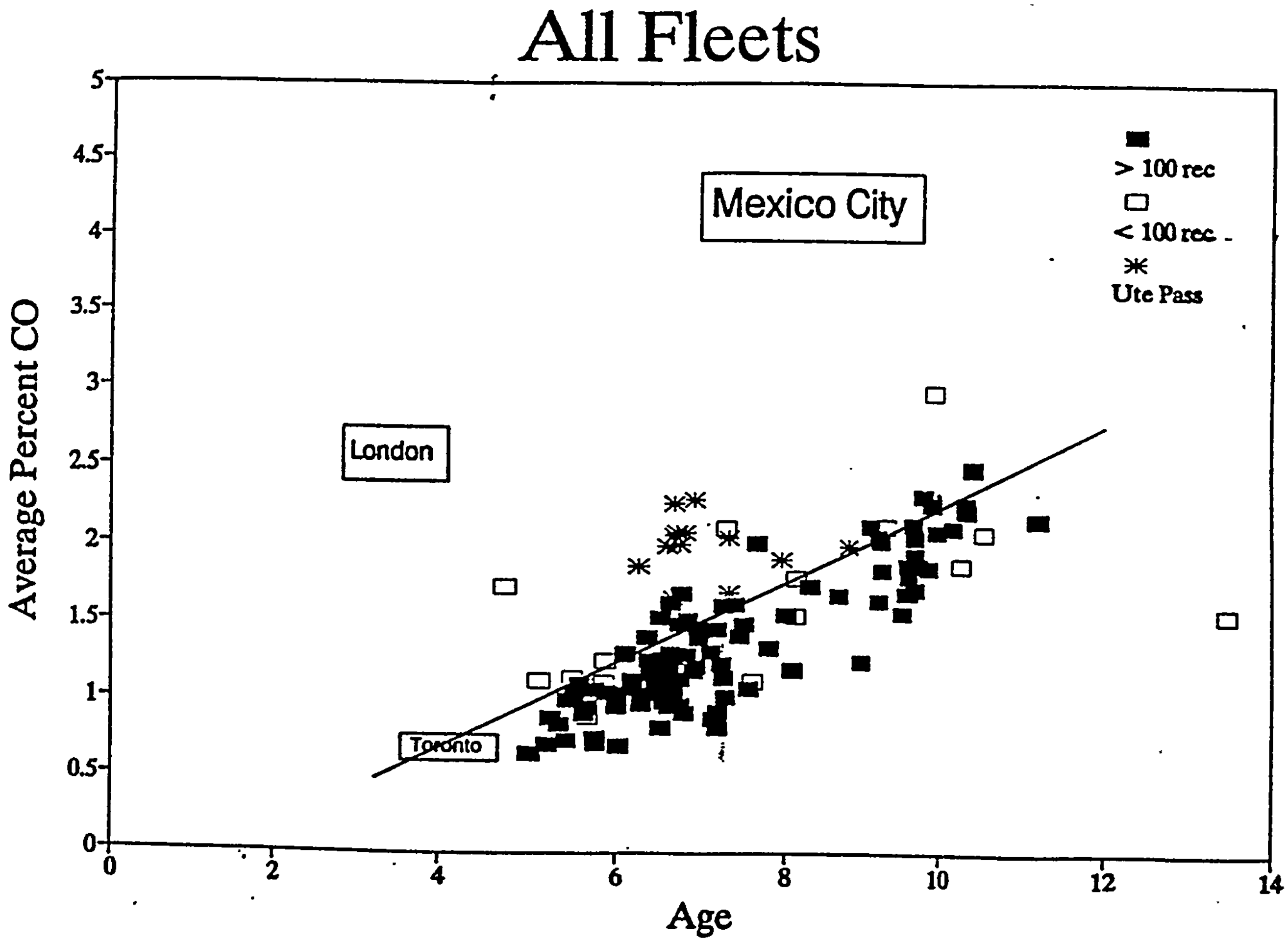

Figure 5. The correlation between % CO emissions and vehicle age for US, UK, and Mexico City fleets. The average age of the Mexico City fleet is estimated to be 6-12 years.

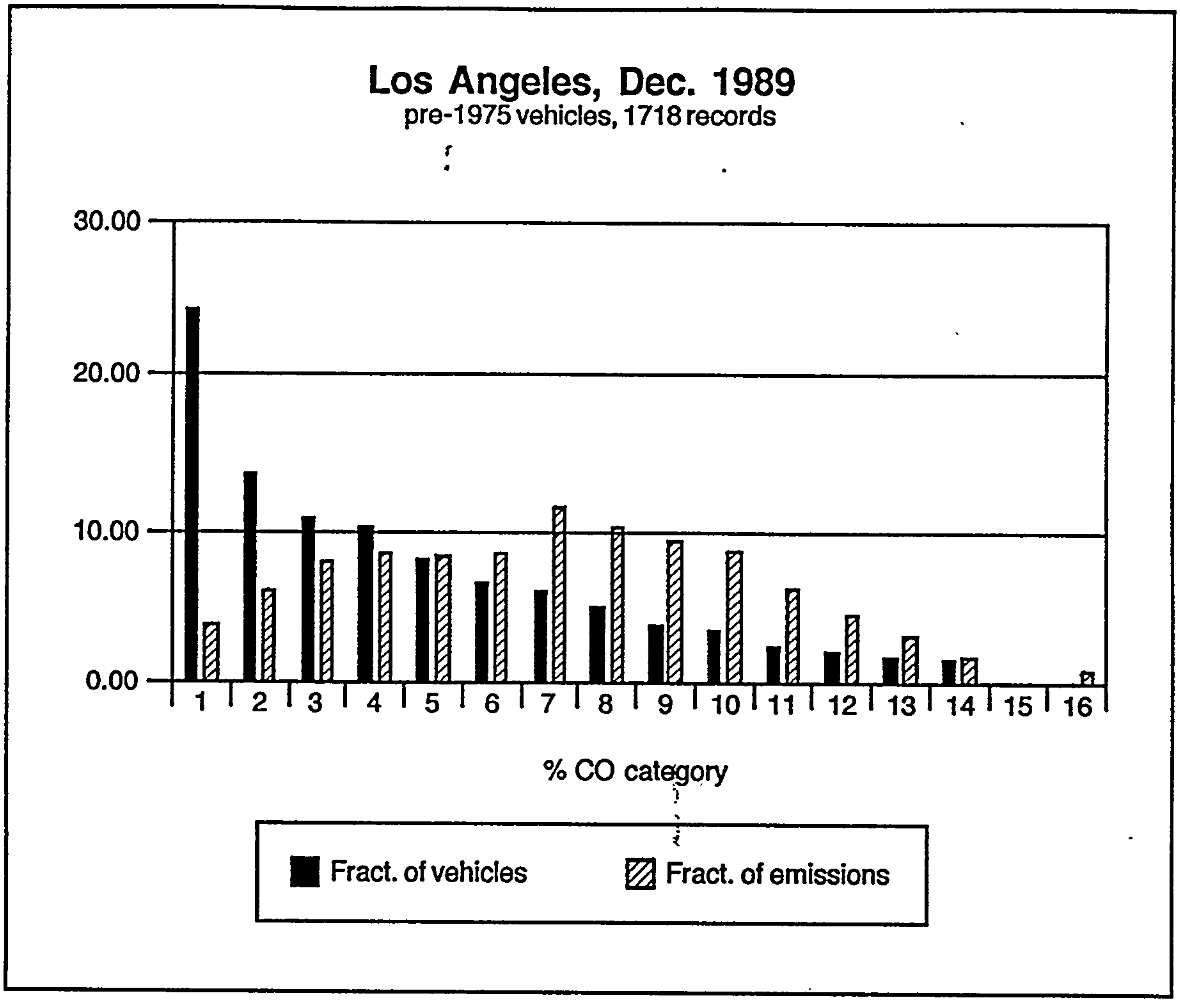

Figure 6. Normalized vehicle numbers and their fractional CO contribution for pre-control U.S. vehicles.

Appendix 2. Conversion table from grams/gallon to grams/mile or grams/kilometer. To convert, find the grams/gallon value in the left column, and the vehicle's mileage, in either miles/gallon or km/gallon, in the top row. The intersection is the grams/mile or grams/km value.

	10	15	20	25	30	35	40	45	50	55	60
50	5.0	3.3	2.5	2.0	1.7	1.4	1.3	1.1	1.0	0.9	0.8
100	10.0	6.7	5.0	4.0	3.3	2.9	2.5	2.2	2.0	1.8	1.7
150	15.0	10.0	7.5	6.0	5.0	4.3	3.8	3.3	3.0	2.7	2.5
200	20.0	13.3	10.0	8.0	6.7	5.7	5.0	4.4	4.0	3.6	3.3
250	25.0	16.7	12.5	10.0	8.3	7.1	6.3	5.6	5.0	4.5	4.2
300	30.0	20.0	15.0	12.0	10.0	8.6	7.5	6.7	6.0	5.5	5.0
350	35.0	23.3	17.5	14.0	11.7	10.0	8.8	7.8	7.0	6.4	5.8
400	40.0	26.7	20.0	16.0	13.3	11.4	10.0	8.9	8.0	7.3	6.7
450	45.0	30.0	22.5	18.0	15.0	12.9	11.3	10.0	9.0	8.2	7.5
500	50.0	33.3	25.0	20.0	16.7	14.3	12.5	11.1	10.0	9.1	8.3
550	55.0	36.7	27.5	22.0	18.3	15.7	13.8	12.2	11.0	10.0	9.2
600	60.0	40.0	30.0	24.0	20.0	17.1	15.0	13.3	12.0	10.9	10.0
650	65.0	43.3	32.5	26.0	21.7	18.6	16.3	14.4	13.0	11.8	10.8
700	70.0	46.7	35.0	28.0	23.3	20.0	17.5	15.6	14.0	12.7	11.7
750	75.0	50.0	37.5	30.0	25.0	21.4	18.8	16.7	15.0	13.6	12.5
800	80.0	53.3	40.0	32.0	26.7	22.9	20.0	17.8	16.0	14.5	13.3
850	85.0	56.7	42.5	34.0	28.3	24.3	21.3	18.9	17.0	15.5	14.2
900	90.0	60.0	45.0	36.0	30.0	25.7	22.5	20.0	18.0	16.4	15.0
950	95.0	63.3	47.5	38.0	31.7	27.1	23.8	21.1	19.0	17.3	15.8
1000	100.0	66.7	50.0	40.0	33.3	28.6	25.0	22.2	20.0	18.2	16.7
1050	105.0	70.0	52.5	42.0	35.0	30.0	26.3	23.3	21.0	19.1	17.5
1100	110.0	73.3	55.0	44.0	36.7	31.4	27.5	24.4	22.0	20.0	18.3
1150	115.0	76.7	57.5	46.0	38.3	32.9	28.8	25.6	23.0	20.9	19.2
1200	120.0	80.0	60.0	48.0	40.0	34.3	30.0	26.7	24.0	21.8	20.0
1250	125.0	83.3	62.5	50.0	41.7	35.7	31.3	27.8	25.0	22.7	20.8
1300	130.0	86.7	65.0	52.0	43.3	37.1	32.5	28.9	26.0	23.6	21.7
1350	135.0	90.0	67.5	54.0	45.0	38.6	33.8	30.0	27.0	24.5	22.5
1400	140.0	93.3	70.0	56.0	46.7	40.0	35.0	31.1	28.0	25.5	23.3
1450	145.0	96.7	72.5	58.0	48.3	41.4	36.3	32.2	29.0	26.4	24.2
1500	150.0	100.0	75.0	60.0	50.0	42.9	37.5	33.3	30.0	27.3	25.0
1550	155.0	103.3	77.5	62.0	51.7	44.3	38.8	34.4	31.0	28.2	25.8
1600	160.0	106.7	80.0	64.0	53.3	45.7	40.0	35.6	32.0	29.1	26.7
1650	165.0	110.0	82.5	66.0	55.0	47.1	41.3	36.7	33.0	30.0	27.5
1700	170.0	113.3	85.0	68.0	56.7	48.6	42.5	37.8	34.0	30.9	28.3
1750	175.0	116.7	87.5	70.0	58.3	50.0	43.8	38.9	35.0	31.8	29.2
1800	180.0	120.0	90.0	72.0	60.0	51.4	45.0	40.0	36.0	32.7	30.0
1850	185.0	123.3	92.5	74.0	61.7	52.9	46.3	41.1	37.0	33.6	30.8
1900	190.0	126.7	95.0	76.0	63.3	54.3	47.5	42.2	38.0	34.5	31.7
1950	195.0	130.0	97.5	78.0	65.0	55.7	48.8	43.3	39.0	35.5	32.5
2000	200.0	133.3	100.0	80.0	66.7	57.1	50.0	44.4	40.0	36.4	33.3