Remote sensing study of motor vehicles' emissions in Mexican Cities

A. Aguilar, V. Garibay & I. Cruz-Jimate
DGICUR, Instituto Nacional de Ecología, Mexico

Abstract

According to the North American Free Trade Agreement (NAFTA), signed by Canada, the USA and Mexico in 1992, beginning on January 1st 2009, Mexico may not maintain restrictions on the importation of used cars older than ten years. The increased influx of used vehicles might cause significant changes in the composition of the country's vehicle fleet and this might increase its contribution to air emissions. Due to this situation and the lack of reliable information for decision-making, in 2007 the National Institute of Ecology of Mexico carried out studies of emissions, activity and composition of the vehicular fleet in the Mexican cities of Mexicali and Tijuana, in Baja California State, which share a border with the USA. Measurements were carried out with an AccuScan RSD3000 remote sensing system for on-road vehicle emissions, to obtain concentrations of carbon monoxide, hydrocarbons and nitric oxide (CO, HC and NO) from exhaust fames. To determine the activity, composition and technological characteristics of vehicles, surveys were conducted and analyses of databases were made. The results show that the average of CO and HC from Mexicali and Tijuana are lower than in the Mexico City Metropolitan Area (MCMA), while the average for NO is higher. This study is the first effort conducted by Mexican environmental authorities to document the impact of imported uses cars in emissions.
Keywords: remote sensing, exhaust emission, vehicle fleet characteristics.

1 Introduction

Emissions inventories are a basic tool to identify the sources of emissions that impact air quality and therefore, these tools are used to design suitable strategies to tackle air quality deterioration [3]. According to the National Emissions

WIT Transactions on Ecology and the Environment, Vol 123, © 2009 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/AIR090181

Inventory of Mexico-1999, transport is the main source of anthropogenic emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs), which are ozone precursors [2]. These sources also release particulate matter (PM) and carbon monoxide. Although the emissions come from fossil fuel (e.g. petrol, gas and diesel) use, there are other factors that determine the amount of emissions from a vehicle such as the technology, the use and driving modes as well as maintenance [5].

Additionally, according to the North America Free Trade Agreement (NAFTA), appendix 300-A.2, starting in January 2009, Mexico may not maintain a ban or restriction on the importation of vehicles manufactured in Canada or the U.S. which are at least 10 years old [14]. When restrictions are removed, it is expected that these vehicles produce significant changes in the vehicular fleet in Mexican cities and, consequently, increase their emissions. Vehicle sales reported by the Mexican association of Vehicles Distributors (AMDA) and reports from the Mexican Tax Management Service (SAT), belonging to the Ministry of Treasury and Public Credit (SHCP), show that from October 2005 to January 2007, in average, two million imported vehicles from Canada and U.S. were legalized. This yields a ratio of two second-hand imported vehicles for each new car sold in Mexico. These vehicles are additional to the non-registered vehicles that were introduced into Mexican territory before 2005 and that are called "*chocolate*", from which there is no information available [11].

Based on this, the Ministry of the Environment and Natural Resources of Mexico (SEMARNAT) is implementing a strategy to reduce the impact of the emissions coming from these vehicles on the air quality of border cities. This strategy includes the vehicular emission verification program, aimed at controlling and reducing on-road vehicle emissions. However, information on vehicle fleet characteristics and emissions levels is necessary to implement these programs.

Due of the lack of reliable information for decision-making in this regard, in 2007 the National Institute of Ecology of Mexico carried out a study to measure on-road emissions from vehicles in Mexicali and Tijuana. A remote sensing device (AccuScan RSD3000) was used to monitor and measure gas concentrations of CO, HC and NO, as well as speed and acceleration. This equipment also takes a picture of the license plate, which allows further vehicle identification and characterization [4]. Finally, an integral analysis of the emissions and driving modes were carried out [6].

2 Experimental section

2.1 Vehicular emissions

Measurements were carried out in 2007, from the 4^{th} to the 10^{th} of October in Mexicali and from the 11^{th} to the 17^{th} of October in Tijuana, monitoring from 9:00 to 14:00 hrs. using an AccuScan RSD3000 system from Environmental System Products, CT, USA. The instrument is built up of a non-dispersive infrared component for CO and HC detection, and a dispersive ultraviolet spectrometer for NO measurements. The RSD process of remotely measuring emissions begins with the light source projecting infrared (IR) and ultraviolet (UV) beams across the road (approximately 15-28 ft) and the Corner Cube Mirror (CCM) returning the transmitted light to a series of detectors. Fuel specific concentrations of HC, CO and NO, as well as smoke in the vehicle exhaust are calculated based on the absorption bandwidth of 3.3, 4.6 and 4.3µm. of IR/UV light [4,10]. During this process, the camcorder system captures and stores the image of the license plate, which can be used to obtain the technical and technological data from the monitored vehicles (e.g. model year, brand, sub-brand, motor size, etc.) [4]; simultaneously, the speed/acceleration sensors (S/A) record the speed and acceleration of the vehicle. Vehicles passed through the selected sites by restricting circulation to one lane, to obtain vehicle speeds of 30 to 40 km/h, [6].

The gas analyzer was calibrated daily with a mixture of certified gases, (CO, propane and NO). The HC measurements were expressed in terms of the "n-hexane ppm equivalent". The CO tolerance was 10% or 0.25% (whichever was greater) for all expected concentrations below 3.0%, and 15% for all CO expected concentrations above 3.0%. In the case of HC, the tolerance was 150ppm or 15% of the expressed HC concentration (whichever was greater) throughout the range of HC concentrations. The NO tolerance was 250ppm or 15% of the expected NO concentration (whichever was greater) throughout the range of the NO concentration [5,6].

To determine the activity, composition and characteristics of the vehicles, surveys were applied. Ten sites were selected in both cities to ensure that they are representative of different socioeconomic strata and diversity of land use.

2.2 Vehicular characteristics and vehicular activity

The aim of the surveys was to determine the size of the vehicular fleet in use and its composition in both cities, distinguishing them by their origin (*national* or *imported)*, as well as their characteristics (model year and vehicle type). The surveys were applied to the drivers at fuel stations, and direct counting was carried out on roads. Complementary data was collected from sales statistics. Surveys were carried out from the 5th to 9th of December 2007 in Mexicali and from the 10th to the 13th of December 2007 in Tijuana, area over the premise that those sites would be in the surrounding were the RSD3000 was installed.

3 Results and discussion

Table 1 shows the total number of readings, as well as the valid readings and readings found per site and per city. 25 369 readings of vehicular emission in total were collected in Mexicali, 5 692 were valid readings (22%). While in Tijuana, 19 951 were collected, from these readings, 4 871 (24%) were valid.

The valid readings were considered those readings that contained data from emissions, speed and acceleration.

Table 1: Number of readings per sampling site per city.

City	Date	Site	Readings	Valid readings		
				All	With plate	Without plate
Mexicali	04-Oct-07	Av. Colón	4 035	685	470	215
	05-Oct-07	Av. Universidad	3 504	583	385	198
	06-Oct-07	Av. Fco. Montejano	3 177	761	521	240
	07-Oct-07	Blvd. Anáhuac	3 408	849	611	238
	08-Oct-07	Av. Río Nuevo	3 628	1 007	654	353
	09-Oct-07	Calle Novena	3 605	666	454	212
	10-Oct-07	Av. Colón	4 012	1 141	766	375
		Total	25 369	5 692	3 861	1 831
		Readings (%)		22	15	7
		Valid readings (%)			68	32
Tijuana	11-Oct-07	Vía Rápida Poniente	5 010	1 092	700	392
	12-Oct-07	Blvd. Casa Blanca	3 928	1 195	735	460
	13-Oct-07	Blvd. Aeropuerto	2 436	529	271	258
	14-Oct-07	Vía Rápida Poniente	1 480	160	83	77
	15-Oct-07	Libramiento Sur	5 091	1 573	877	696
	16-Oct-07	Paseo Ensenada	2 006	322	186	136
		Total	19 951	4 871	2 852	2 019
		Readings (%)		24	14	10
		Valid readings (%)			59	41

Ideally, the measurement of vehicular emissions should be carried out when the vehicle experiences a light increment in the speed, preferable on a road whit a slight slope [8]. In the case of CO and especially for HC, emissions can increase with the load on the engine from moderate to high, that is, when the vehicle increases its speed from moderate to high. HC emissions can also increase during decelerations [9]. NO is primarily formed in the post-flame of the gases during the combustion process into the cylinder engine. The kinetic of this reaction is highly dependant of the temperature of the gas; high temperatures favour the rate of formation of NO [7]. Nitrogen oxide emissions can also be increased when there is a load on the engine and with a high air/fuel mixture [1].

Regarding pollutants emissions, the average CO volume percentage was 0.70% for Mexicali and 0.83% for Tijuana while HC emissions for Mexicali were 132 ppm and 130 ppm for Tijuana. On the other hand, the behaviour of NO emissions for both cities was, for Mexicali 1,200 ppm and Tijuana 966 ppm. Table 2 shows the summary of the average, standard deviation and confidence interval of the emissions data as well as speed and acceleration for both cities.

On the emissions report the vehicular fleet was classified based on the technological stratum that represents the technologic characteristics and emission control system. For the 1981-1990 stratum, these vehicles did not have emission control systems; while for stratum 1991-1992, when legislation for control emission started, these vehicles had two-way catalytic converters installed.

Table 2: Summary of speed, acceleration and emissions per city.

City (No. valid data)	Parameter	CO (vol %)	HC (ppm)	NO (ppm)	Speed (km/h)	Accel. (km h^{-1} s^{-1})
Mexicali (5 692)	Average	0.70	131.85	1,200.86	29.65	2.52
	SD	1.39	170.44	1,170.33	6.08	1.19
	±95% CI	0.12	14.17	97.27	0.51	0.10
Tijuana (4 871)	Average	0.83	129.84	965.79	28.61	2.07
	SD	1.60	209.33	892.80	6.55	1.14
	±95% CI	0.14	18.81	80.21	0.59	0.10

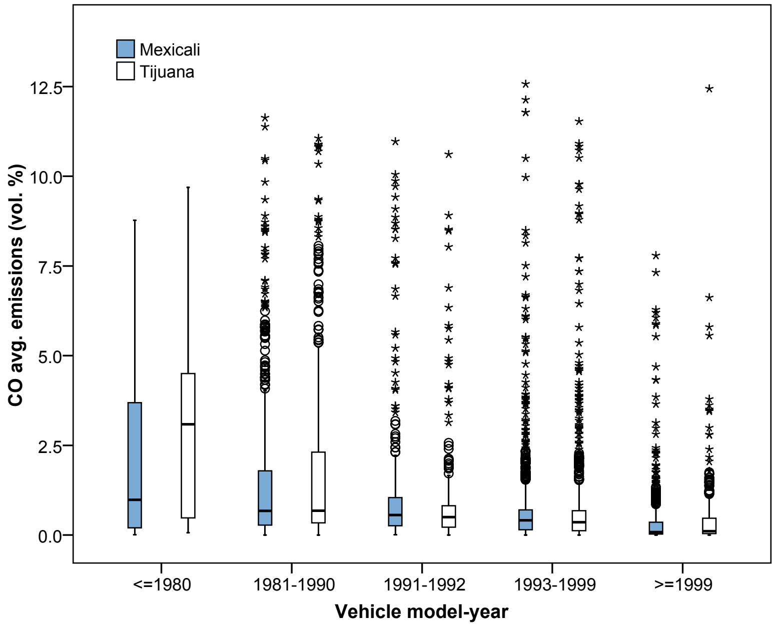

Figure 1: CO emission per vehicular stratum and per city.

Finally, from the 1993 model year vehicles were equipped with three-way catalytic converters and electronic fuel injection.

Based on this classification, emissions of CO (% vol.), HC (ppm) and NO (ppm) per vehicular stratum and per city are presented in fig. 1-3. It is observed that the mean vehicular emissions per stratum show a decrease trend that can be explained by the improvement in the emission control systems. The average values of CO and HC were very similar in Mexicali and Tijuana, while NO was higher in Mexicali.

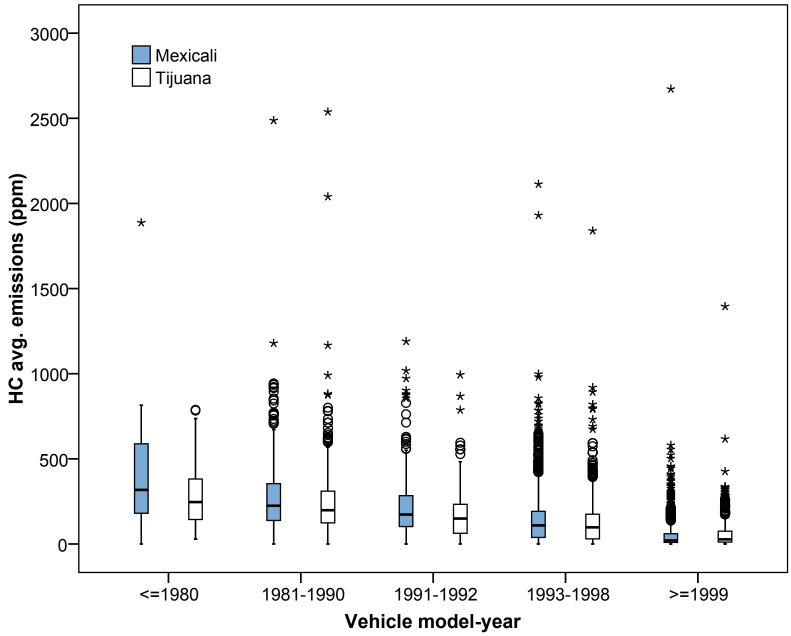

Figure 2: HC emission per vehicular stratum and per city.

Regarding data dispersion, observed even in the technological strata (1983-1999 y >=1999) that has the best control emission technologies, the major data dispersions are found in the model year 1998 and earlier, that is more than 10 years of age. That largest data dispersion can be associated with the age, the vehicle's maintenance, the driving modes and the lack of an inspection and emission control program. In Mexicali and Tijuana there are no inspection and maintenance program, which is reflected in the significant dispersion of emission values.

The survey conducted in Mexicali and Tijuana, show that 80.7% of on-road vehicles in Mexicali were originally purchased, as new vehicles, in the U.S., while in Tijuana it represents 80.9% [12], which means that for every purchased vehicle in Mexico there are 4 imported used vehicles.

The composition of the vehicular fleet is shown in fig. 4 along with a comparison between Mexicali, Tijuana and MCMA, where there is less penetration of foreign vehicles. It is observed that in Mexicali, 55% of the fleet is older than 10 years, while in Tijuana 63%. In contrast, MCMA 41% of its fleet is older than 10 years. Therefore, MCMA has a higher percentage of vehicles on the last stratum (>=1999).

When the average emissions were compared per city and type of vehicle, in general, in Tijuana CO emissions were higher than in Mexicali, especially for pick-up while HC emissions were higher for SUV/VAN in Mexicali compared to other type of vehicles in both cities. In Mexicali, NO emissions were always higher than in Tijuana.

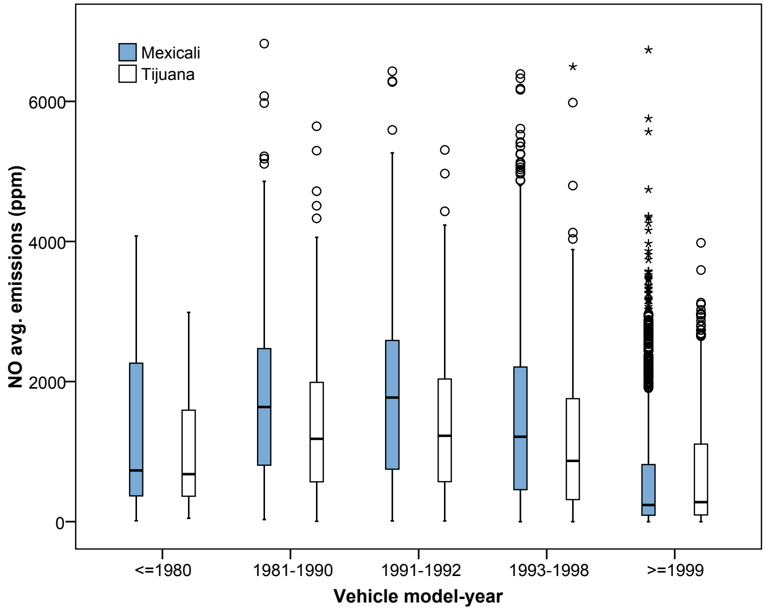

Figure 3: NO emission per vehicular stratum and per city.

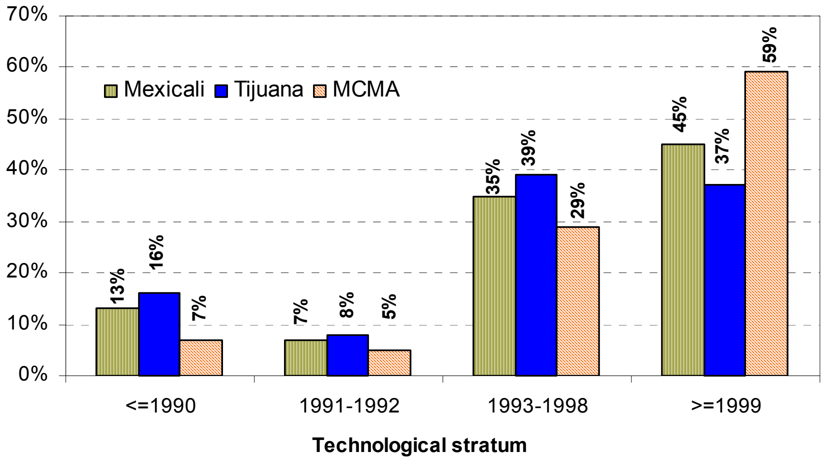

Figure 4: Vehicular stratum classification.

Comparing mean emissions of the three pollutants in the three cities, similar values are observed for CO and HC, while NO is higher in Mexicali, this result match with the ones found in table 3 for NO. However, according to preliminary results of an RSD study carried out in the MCMA in 2006, which remains unpublished [13], it is expected that the data dispersion would be minor in the MCMA compared with Mexicali and Tijuana.

Table 3: Summary of speed, acceleration and emissions per city.

City	Type of vehicle/(n)	CO (vol %)	HC (ppm)	NO (ppm)
Mexicali	Pick up (442)	0.75	132.20	1,320.65
	Sedán (2,509)	0.74	144.33	1,228.70
	SUV/VAN (910)	0.75	174.67	1,473.74
Tijuana	Pick up (384)	1.16	159.86	985.20
	Sedán (1 504)	0.79	135.92	1,041.23
	SUV/VAN (964)	0.92	138.88	1,125.49

Table 4: Mean emissions comparison between MCMA, Mexicali and Tijuana.

Location	CO (vol %)	HC (ppm)	NO (ppm)
MACM, 2005	0.88	156	965
Mexicali, 2007	0.70	132	1,201
Tijuana, 2007	0.83	130	966

4 Conclusions

Results of vehicular emissions and characteristics study show that the importation of used vehicles in Mexicali and Tijuana has a major impact on the composition of its vehicle fleet in terms of age, mechanical condition and vehicle type. This change has caused a great dispersion in the values of emission, reflecting the need to regulate the vehicle emissions. Moreover, based on the results of this study, Mexican environmental authorities have elements to document and implement actions to regulate the importation of used vehicles in Mexico.

References

[1] Peavy H.S. & Rowe, D.R., *Environmental Engineering*, McGraw-Hill: USA, pp. 563-565, 1996.

[2] INE, *Inventario nacional de emisiones de México, 1999,* SEMARNAT: México, pp. xxi-xxxi., 2006.

[3] Selman, P., *Environmental planning*, SAGE publications Ltd: UK, pp 261-262, 2000.

[4] RSD, *Correlation and Remote Sensing Device Application Results. A Summary of the Milestones Reached*, ESP-Environmental Systems Products: USA, full document, 2005.

[5] Shifter I., Díaz L., Mugica V. & López-Salinas E., Fuel-based motor vehicle emissions for inventory metropolitan area of Mexico City, *Atmospheric Environment,* **39**, pp. 931-940, 2005.

[6] Bishop, G.A., Stedman, D.H., De la Graza J. & Dávalos F., On-road remote sensing vehicles emissions in Mexico, *Environmental science & Technology*, **31**, pp. 3505-3510, 1997.

[7] Schifter, I., Díaz, L., Durán, J., Guzmán, E., Chávez, O. & López-Salinas, E., Remote Sensing Study of Emissions from Motor Vehicles in the Metropolitan Area of Mexico City, *Environmental Science & Technology* **37**, pp 395-401, 2003.

[8] Bohren, L., Profile of Vehicles at the Border Crossings between Tijuana, Mexico and San Diego, California. *Proc. of the 93rd Annual Conference & Exhibition*, eds. (CD version): Salk Lake City, pp. full document, 2000.

[9] McClintock, P.M. *The Colorado Enhanced I/M Program 0.5% sample Annual Report*; Prepared for The Colorado Department of Public Health and Environment: Tucson, AZ, January 27, 1998.

[10] EPS-Environmental Systems Products, *Remote Sensing Milestones, "US Experience"* Niranjan Vescio, ESPH August 12, 2004.

[11] SEMARNAT, *Importación definitiva de autos usados. Consecuencias e impactos ambientales*. Documento de trabajo. Subsecretaría de Gestión para la Protección Ambiental, Dirección General de Gestión de la Calidad del Aire y RETC, Dirección de Calidad del Aire, México, D.F. 2007.

[12] TSTES, S.A. de C.V., *Estudio de emisiones y características vehiculares en ciudades mexicanas de la frontera norte*. Documento de trabajo. Elaborando para el Instituto nacional de Ecología bajo contrato INE/ADE-077/2007, México, D.F. 2007.

[13] Personal communication, Gobierno del Distrito Federal, Secretaría del Medio Ambiente, 2008

[14] Appendix 300-A.2 North American Free Trade Agreement [NAFTA] signed the 17th of December of 1992, www.sice.oas.org/trade/nafta/naftatce.asp