EVALUATION OF PM EMISSIONS FROM VEHICLES IN THE BORDER REGION

PROJECT NUMBER: A-01-04

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NARRATIVE SUMMARY

The investigators developed a system to measure emission factors of particulate matter (PM) concentration and composition during roadside sampling in four cities along the U.S.-Mexican border, including Calexico, Mexicali, El Paso, and Ciudad Juárez. The measurement system included a photoacoustic analyzer for black carbon (BC), a photoelectric aerosol sensor for particle-bound polycyclic aromatic hydrocarbons (PAHs), a DustTrack for particulate mass, and a carbon dioxide (CO_2) analyzer. When a vehicle with measurable emissions passed the system's probe, corresponding BC, PAH, PM mass, and CO_2 peaks were evident, and a fuel-based emission factor was estimated. A picture of each vehicle was also recorded with a digital camera. The advantage of this system, compared to other roadside methods, is the direct measurement of PM components and reduced interference from roadside dust.

The study revealed some interesting trends: busses and medium-duty trucks were more frequently identified as high PM emitters than heavy-duty trucks or passenger vehicles. Mexican trucks and buses had higher average emission factors compared to U.S. trucks and buses, although the study was too small to determine if the differences were statistically significant. Few passenger vehicles had measurable PM emissions, although the highest emission factor came from an older model passenger vehicle licensed in Baja California.

The emission factor results indicate that buses and medium-duty vehicles are more frequently high emitters of PM compared to heavy-duty or passenger vehicles. In the border region, buses and medium-duty vehicles could benefit from further study and perhaps an inspection and maintenance program. This study did not illustrate significant differences in PM emissions with the country of origin. This could be because of the small size of the study, the focus on diesel engines, and/or the number of vehicles without legible license plates.

This work was presented at the EPA Region 9 SCERP meeting, and the researchers in Mexicali and Calexico have invited the researchers from the University of Utah to talk about the study's findings to local policy makers. These results are also being drafted into a paper for submission to the *Journal of the Air & Waste Management Association.*

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INTRODUCTION

Concern has been growing about air pollution generated by the increasing number of vehicles traveling in the U.S.-Mexico border region. In fact, the number of trucks crossing into the United States from Mexico increased from 2.1 million in 1992 to 3.7 million in 1998 (Ganster and Pijawaka 2000). Emissions from these vehicles will continue to play an important role in the air quality of the region and, consequently, the health of the region's 13 million residents. Many of these residents are currently exposed to high levels of air pollution in the form of ozone (O_3), particulate matter (PM), carbon monoxide (CO), and sulfur dioxide (SO_2) (Ganster and Pijawaka 2000).

An increasing amount of evidence shows the negative health effects associated with fine particulate matter (Dockery, et al. 1993; Tolbert 2000; Peters, et al. 2001). Some of the most common sources of fine particulate matter are gasoline- and diesel-fueled vehicles. Furthermore, the size and composition of particles are key factors in determining their associated health effects. For example, particulate emissions from combustion sources contain polycyclic aromatic hydrocarbons (PAHs), which are reasonably anticipated to be carcinogens (NTP 2003), and elemental carbon (closely related to black carbon) has been linked to adverse cardiac effects (Tolbert, et al. 2000). Currently, the city of El Paso and the Imperial-Mexicali Valley exceed the national PM_{10} standard (EPA 2003), and preliminary data show that El Paso and Imperial Valley are close to the annual mean $PM_{2.5}$ cutoff (EPA 2000). In Mexicali, PM_{10} concentrations contribute significantly to asthma and acute respiratory infections hospitalizations (Reyna, et al., in press).

The EPA has found that 10% to 30% of vehicles cause the bulk of automobile pollution and that the percentage of high-emitting vehicles increases with vehicle age (EPA 1993). Furthermore, Morris, et al. (1998) report that 20% of heavy-duty diesel vehicles are responsible for 35% of emissions. Typically, these high emitters are identified by cross-road infrared measurements of CO in vehicle (Stedman, et al. 1998. Some studies of high CO emitters have been conducted in Mexico (Bishop, et al. 1997). In the United States, limited measurements of road-side particulate emissions from vehicles have been conducted (Kieslar, et al. 2002; Cadle, et al. 1997), and Cadle, et al. (1997) report a more than 300-fold variation in PM_{10} emission factors.

The border region is a particularly interesting region for studying PM emissions from vehicles. The EPA reports that roughly 30% of 5-year-old cars emit excessive pollution, whereas 55% of 7-year-old vehicles are high emitters. In northern Mexico, the number of vehicles is increasing. Mexican vehicles are on-average older than U.S. vehicles. Furthermore, a large fraction of these vehicles do not comply with U.S. or Mexican emission standards (Ganster and Pijawaka 2000). For example, Ghosh, et al. (1998) report that one in five passenger vehicles lacks a catalytic converter.

RESEARCH OBJECTIVES

The objective of this study is to evaluate a new roadside method for measuring black carbon (BC), particle-bound PAHs, and PM mass emissions from vehicles. The system was designed to obtain emission factors from a large number of vehicles and to minimize interference from dust, which is particularly important in arid environments. The study focused on identifying vehicles that emitted high quantities of PM, with an ultimate goal of providing policy makers with preliminary results that will help focus air pollution control measures.

RESEARCH METHODOLOGY/APPROACHES

The investigators collected PM emissions and vehicle information during two field tests conducted in Calexico-Mexicali and El Paso-Ciudad Juárez during March 2002. In each city, the sampling locations were selected to capture emissions from a variety of vehicle types (Table 1).

Calexico (population 27,109) is a small city in California across the border from Mexicali (population 790,433). Because Mexicali is so much larger than Calexico and because of inclement weather, the investigators selected one sampling location in Calexico and four in Mexicali. Ciudad Juárez (population 1 million) and El Paso (population 1 million) are located across the border from each other (INEGI 1999), and three sampling locations were selected in each location.

In general, the vehicles fell into four classes: buses; passenger vehicles; heavy-duty vehicles, which included 18-wheeled trucks; and medium-duty vehicles, which included dump trucks, fire trucks, tow trucks, and cement trucks. Ideally, each sampling location had a favorable wind direction for sampling, moderate traffic density, and a close proximity to traffic. If the traffic was too heavy, it was not possible to differentiate one PM peak from another. A favorable wind direction was necessary to collect any emissions data.

Initial testing revealed that few passenger vehicles emitted significant amounts of BC or particle-bound PAHs; therefore, the focus shifted to other vehicle categories. For buses and heavy- and medium-duty vehicles, the investigators took a picture of each vehicle and wrote down the time, a brief vehicle description, the country of origin (if visible), and whether there were visible emissions. The digital pictures contained a time stamp for later integration. This information was collected for passenger vehicles only if they exhibited visible emissions. At locations with heavy traffic, the investigators took several 10-minute traffic counts, and took pictures and noted relevant information of vehicles that were potentially high emitters. The country of origin was divided into two classes—U.S. and Mexico—based on the license plate. In a number of cases, license plates were not visible or vehicles had license plates from the U.S. and Mexico.

Figure 1 illustrates the emission measurement setup. Briefly, the investigators located their instruments downwind of the traffic in a roadside pullout or other close location. The instruments included a DustTrack (DT, TSI Inc.), a photoacoustic analyzer (Arnott, et al. 2000), a photoelectric aerosol sensor (PAS, EcoChem Inc.), and a California Analytic CO/CO_2 analyzer. Each of the instruments pulled its sample through a single 3/8" copper probe. All of the equipment was mounted in a van that could move to different locations as needed. Furthermore, the sampling probe could be moved to different heights to capture emissions from heavy-duty vehicles or emissions from passenger vehicles and buses.

A TSI DustTrack (DT) provided $PM_{2.5}$ particle mass concentration of particles with aerodynamic diameters less than 2.5 µm. It operates by measuring 90-degree light scattering at 780 nanometers (nm) and correlating this to mass concentration. Its results also correlate well with filter measurements of diesel exhaust (Moosmüller, et al. 2001). In addition, real-time particulate-bound PAH concentration measured with the PAS 2000 (Burtscher 1992). The PAS operates on the principle that particle-bound PAHs release electrons upon irradiation with UV light. The positively charged particles are collected on a filter, where the charge is measured, and charge corresponds to the concentration of PAHs. Furthermore, real-time BC (soot concentration) of particulate matter measured with a photoacoustic analyzer (PA) (Arnott, et al. 1999, 2000). The PA directs a laser at particles that enter the instrument, and BC/soot absorbs the light generated by the laser. The light-absorbing particles convert light to heat, producing a sound wave. A sensitive microphone measures the quantity of light absorption and thus BC. In order to calculate fuel-based emission factors, the investigators measured CO/CO_2 emissions. The CO_2 monitor operates on the principal that CO absorbs infrared light.

One major advantage of measuring black carbon and particle-bound PAHs is that BC and PAH emissions are combustion products and can differentiate engine emissions from entrained road dust or other atmospheric dust. When a vehicle that emitted detectable amounts of PM passed near the probe, a BC, PAH, PM, and CO_2 peak would appear a few seconds later. When selecting peaks, the investigators focused on BC and PAH peaks, and selected peaks for which the BC concentration exceeded 10 $\mu g/m^3$, which was significantly above background levels. All of the instruments continually logged time-stamped data, and the individuals collecting vehicle information and taking digital pictures also used these time stamps. Later, the peaks, vehicle pictures, and vehicle information were integrated. From all of this data, emission factors were estimated as in the following example.

Example
Figure 2 illustrates an example BC and CO_2 peak, from which a BC emission factor could be calculated. The area under the CO_2 and BC curves were calculated using the trapezoidal rule, as in the following example.

The trapezoidal rule is given by:

$$\boxed{I = \left(\frac{y_1 + y_n}{2} + \sum_{i=2}^{n-1} y_i \right) \Delta x}$$

Where,
y_1 = the y-axis value at the initial time.
y_n = the y-axis value at time n.
yi = the y-axis value at time i.
Δx = the change in time. For this example Δx is 3 seconds and remains constant.

When calculating the CO_2 emissions by integrating under the curve, first the background CO_2 concentration of 370 parts per million (ppm) is subtracted from all of the values. This makes y_1 and y_n equal to zero and eliminates the first term in the equation, leaving:

$$I \quad = \quad (5+17+25+26+18+5)(ppm) \quad x \quad (3)(\sec)$$

I = 288 ppm-sec

Multiplying by the CO_2 analyzer flowrate of 1.45 liter/minute and converting the units will yield a CO_2 concentration of 6.96×10^{-9} m^3. Using the ideal gas law, the CO_2 volume is converted to moles

$$n=PV/RT$$

where,

n = the moles of CO_2
P = the pressure, 101 kPa
V = the volume of CO_2, 6.96×10^{-9} m^3
R = the ideal gas constant, 8.314 kPa-m3/(kmol K).
T = the temperature, 301 K

Therefore,

$$n = 2.81 \times 10^{-10} \text{ kmoles } CO_2$$

Using the following reaction as an approximation:

$$CH_2 + \frac{3}{2}O_2 \rightarrow CO_2 + H_2O$$

One mole of CO_2 corresponds to one mole of fuel, and 2.81 x 10^{-10} kmoles of fuel are consumed to generate the corresponding black carbon peak. Converting the moles of fuel to a mass using the molecular weight of CH_2 (14 g/mol) yields 3.94 x 10^{-9} kg of fuel burned. Integrating under the BC curve using the trapezoidal rule described above, multiplying by the analyzer flowrate of 1 l/min, and converting yields units 1.18 x 10^{-3} µg BC for every 3.94 x 10^{-9} kg of fuel burned. This converts to an emission factor of 0.301 g black carbon/kg fuel. The investigators developed a program to automatically calculate emission factors from the raw data.

PROBLEMS/ISSUES ENCOUNTERED

The biggest problem encountered during the study was the high-wind conditions in Calexico. This caused the researchers to miss two days of sampling. In addition, at some locations it was difficult to resolve differences in the peaks when traffic volume was heavy, but during the course of the study the researchers were able to select better sampling sites, which reduced these problems. Finally, a number of vehicles were missing license plates or had illegible license plates.

RESEARCH FINDINGS

Ambient Results

Figure 3 presents average $PM_{2.5}$ and BC concentrations at the sampling locations. High BC concentrations tend to be correlated with urban locations and moderate to heavy traffic, whereas $PM_{2.5}$ concentrations are more widely variable. This is expected because BC comprises a large portion of diesel PM (Kittelson 1988) and should closely relate to the presence of diesel exhaust. However, total PM can contain dust and PM from other types of sources. PAHs are a product of incomplete combustion, and PAH concentrations exhibit similar trends to the BC concentrations.

Emission Factors

A total of 152 vehicles emitted measurable quantities of BC, PAHs, and/or $PM_{2.5}$, and the number of emission factors calculated per location was similar, although it varied somewhat with location and weather conditions. Because of the short duration of the study, sufficient data could not collected to perform a relevant statistical analysis. The study was also complicated by the number of vehicles without license plates or with unreadable plates. However, the results illustrate some interesting trends, including:

- The relative percent of vehicles in each class with measurable emission factors
- The vehicles with the largest emission factor in each location
- Average emission factors by vehicle type

Few passenger vehicles in the United States or Mexico exhibited measurable quantities of PM; however, the highest emitter of the study was an older model passenger vehicle, with emissions of 15.2 g $PM_{2.5}$/kg fuel (13 g $PM_{2.5}$/kg C in fuel), which is 150 times higher than the average emission factor for light-duty vehicles (0.085 g $PM_{1.9}$/kg C) reported by Allen, et al. (2001). Because of the small number of passenger vehicles with measurable emissions, the researchers focused their efforts on the other three vehicle classes.

Figure 4 shows the breakdown of vehicles with measurable emissions by vehicle class. It also shows a larger percentage of medium-duty vehicles and buses with measurable emissions compared to heavy-duty or passenger vehicles. This was supported by observations of the vehicle classes; heavy-duty vehicles appeared newer and better maintained than buses or medium-duty vehicles, particularly dump trucks. Figure 4 also indicates that a similar fraction of U.S. and Mexican buses and trucks had measurable emissions; however the emissions from Mexican buses were likely underestimated (see discussion of bus results below).

For additional detail, Table 2 contains the number of vehicles for which an emission factor could be calculated, the country of origin, and vehicle class. Table 3 shows the maximum emission factor for each sampling location. They are generally higher than the average emission factor reported by Allen, et al. (2001) (0.788 g $PM_{1.9}$/kg of C for heavy-duty vehicles). It is surprising that the BC emission factors exceed the $PM_{2.5}$ emission factors in Table 3. One potential reason is that the background PM levels could interfere with the estimation of a PM emission factor. In addition, the DustTrack uses a particle density to calculate particle mass, and diesel particle densities can range from 0.5 to greater than 2.0 g/cm^3 (Shi, et al. 2001). A particle density was not available for this study, so the DustTrack default values were employed.

In some cases, the investigators targeted locations with high concentrations of buses and heavy-duty vehicles, and the average emission factors and standard deviations are summarized in Table 4. Passenger vehicles and medium-duty vehicles were not included in the table because passenger vehicles rarely emitted measurable quantities of PM and there were only a small number of medium-duty vehicles.

Heavy-Duty Vehicle Results

One of the goals of this study was to investigate potential differences between the PM emissions from heavy-duty vehicles licensed in the U.S. versus those licensed in Mexico, thus, several sampling locations were selected near truck border crossings to investigate these differences. However, the number of vehicles was too small to identify differences between the number of vehicles with measurable emissions depending on where they were licensed, and the number of vehicles of unknown origin often overshadows the small differences. For example, comparing results from the truck exit of the U.S. customs in El Paso shows that 8% of U.S. heavy-duty vehicles had measurable PM emissions and 12% of Mexican heavy-duty vehicles had measurable PM emissions (Figure 4). The average emission factors for this location (CustX, Table 4) were higher for Mexican heavy-duty vehicles, but only two U.S. heavy-duty vehicles had measurable emission factors. Furthermore, approximately 25% of the heavy-duty vehicles had missing or unreadable license plates at the CustX location. At the Calexico border crossing, the Mexican heavy-duty vehicles had higher BC emission factors but similar PAH emission factors, although most of the Mexican heavy-duty vehicles also had U.S. license plates. When looking at the average emission factors, they varied widely with large standard deviations; therefore, a much larger sample size would be needed to determine whether the differences in average emission factors are significant.

In addition to sampling locations near truck border crossings, the investigators collected emissions data from Salt Lake City because it is well outside of the border zone where Mexican trucks travel. A total of 20% of heavy-duty vehicles had measurable emissions in Salt Lake City, which was greater than any other U.S. or Mexican location. This is likely because the sampling location was an interstate on ramp, where vehicles were accelerating rapidly. However, the average emission factors were lower at the Salt Lake City location than at any of the other locations (Table 4).

Medium-Duty Vehicle Results

Although the investigators saw fewer medium-duty vehicles compared to other categories, a larger percentage had measurable emissions compared to heavy-duty vehicles (Figure 4). Most of the medium-duty vehicles appeared to stay in their country of origin; therefore, vehicles without license plates were assumed to be from the country where the sampling occurred. From visual observations, these heavy-duty vehicles tended to be older and less well-maintained than the heavy-duty vehicles that were typically seen crossing the border. In addition, more medium-duty vehicles, especially dump trucks, were seen in Mexicali and Ciudad Juárez than in El Paso or Calexico. This may be a function of the sampling location or the vehicle inventory in the region.

Bus Results

Buses tended to emit higher quantities of PM compared to heavy-duty or passenger vehicles. Figure 4 shows that the rates of measurable emissions were 13% in both the United States and Mexico. However, the results probably underestimate the number of buses with measurable emissions in Mexicali and Ciudad Juárez because of the unpredictable location of the exhaust. Many buses had multiple tailpipes, and it was difficult to determine where the exhaust vented. In some cases, the exhaust vented above the roof of the bus, and in others it vented at ground level. Sometimes the exhaust did not vent through any of the tailpipes, instead venting underneath the body of the bus. Calexico buses were not captured in the study because of bad weather and because Calexico is a small town with little bus traffic compared to Mexicali.

The bus emission factors were higher for the three locations in Mexico compared to those estimated for the one location in El Paso. However, the Viscount (El Paso) results did not include one high emission factor from an El Paso bus whose driver stopped to talk with the researchers about the study and then accelerated rapidly. Some of the differences in emission factors between the U.S. and Mexican bus emissions may be due to the traffic conditions, as well differences in the age and maintenance of the two fleets. The standard deviations for the buses were also greater for the Libertad, very slow moving traffic; and Juan, accelerating traffic; compared to Viscount, constant speed traffic; or Anahuac, decelerating traffic.

The investigators saw more bus traffic in Ciudad Juárez and Mexicali than Calexico or El Paso. In the study by Gosh, et al. (2000), residents of Mexico reported taking public transportation more frequently than residents of the United States.

Regional Vehicle Fleets

Table 5 details the population of vehicles in Mexicali and their daily mileage from 1996. Overall, passenger vehicles dominate the vehicle fleet in terms of numbers, but high-PM emitters are most commonly identified in the other vehicle classes. Mexicali has approximately 215,000 passenger vehicles, 7,000 light-duty trucks, 1,000 buses and 16,000 heavy-duty vehicles. It is interesting to note that buses travel twice as much annually as any of the other vehicle classes. Therefore, in spite of the small numbers of buses, the high annual mileage makes buses a more important factor in PM emissions. More recent studies indicate that the vehicle fleet contains approximately 326,871 passenger vehicles (Gobierno del Estado de Baja California 2003) and 917 buses (Municipio de Mexicali 2003).

The Texas Commission on Environmental Quality (TCEQ) reports that Ciudad Juárez has ,3786 buses, with 61.8% using diesel fuel and 38.2% natural gas or propane. It also has 4,382 heavy-duty vehicles and 933 light-duty trucks.

CONCLUSIONS

The investigators identified 152 vehicles with measurable PM emissions, illustrating that the sampling system can identify high-PM emitters from roadside locations. The sampling system, comprised of a photoacoustic analyzer, PAS 2000, DustTrack, and CO_2 analyzer, could successfully differentiate between vehicle emissions and entrained road dust. However, it did have a few disadvantages: the requirement of favorable wind direction and the inability to resolve emissions when more than one vehicle traveled closely together. The emission factor results indicate that buses and medium-duty vehicles are more frequently high emitters of PM compared to heavy-duty or passenger vehicles. In the border region, buses and medium-duty vehicles could benefit from further study and perhaps an inspection and maintenance program. This study did not illustrate significant differences in PM emissions with the country of origin. This could be because of the small size of the study, the focus on diesel engines, and/or the number of vehicles without legible license plates.

RECOMMENDATIONS FOR FURTHER RESEARCH

This study identified several classes of vehicles, namely buses and medium-duty vehicles, that emitted comparatively large quantities of PM compared to other vehicle classes. These classes of vehicles would make good targets for additional study and potential policy actions, such as an inspection and maintenance programs.

RESEARCH BENEFITS

One of the biggest benefits of this project was the identification of vehicles that emit much higher-than-average quantities of PM, given that the areas studied are greatly affected by PM levels. The study also identified one potential area for cost effectively reducing PM emissions. Although these preliminary results need verification, they can be used by local policy makers for targeting certain classes of vehicles for future studies and eventual policy actions, possibly including inspection and maintenance programs for all on-road vehicles that are larger than passenger vehicles. Buses could be particularly promising candidates, given the small fleet numbers and the large annual mileage.

Eventually, these types of results could also be used for modeling air emissions from the region's vehicle fleets. Models of air emissions from vehicle fleets such as EPA's MOBILE 6 model have provisions for specifying a fraction of vehicles with much higher-than-average emissions, and these preliminary results can provide some indication of the percentage of vehicles with excess emissions.

This work was presented at the EPA Region 9 SCERP meeting, and the researchers in Mexicali and Calexico have invited the researchers from the University of Utah to talk about the study's findings to local policy makers. These results are also being drafted into a paper for submission to the *Journal of the Air & Waste Management Association.*

This project supported the collaboration between researchers at the University of Utah, the Universidad Autónoma de Ciudad Juárez, the Universidad Autónoma de Baja California, and the Imperial Valley campus of San Diego State University. It was the first time these researchers have worked together, and the groups in Utah, Mexicali, and Imperial Valley have joined together to perform an additional SCERP project. The study also supported the training of several students who assisted with traffic counts, collecting emissions data, and analyzing the results.

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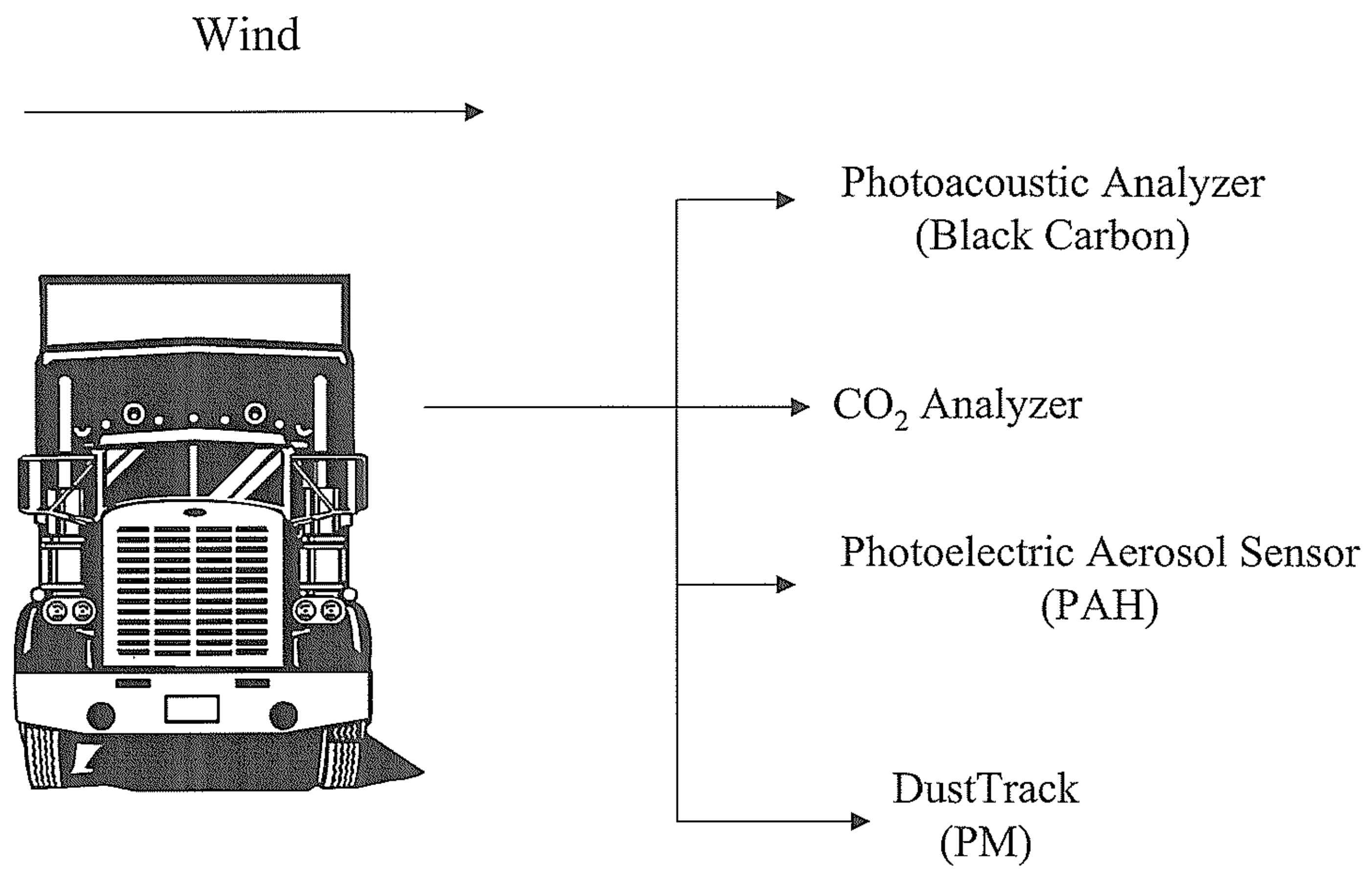

Figure 1. Sampling Set-up

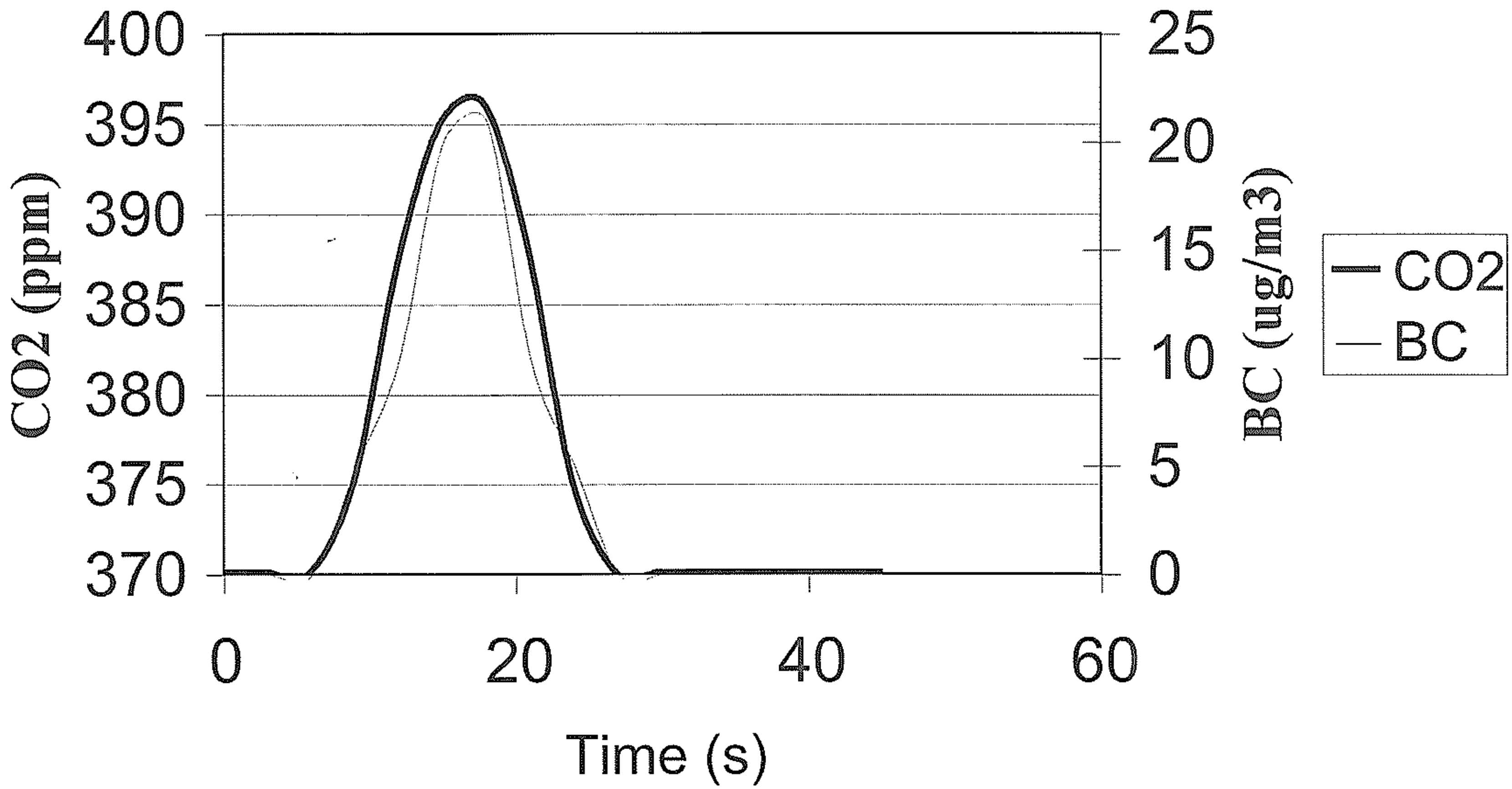

Figure 2. Example of a Black Carbon and CO2 Spike from which an Emissions Factor are Calculated

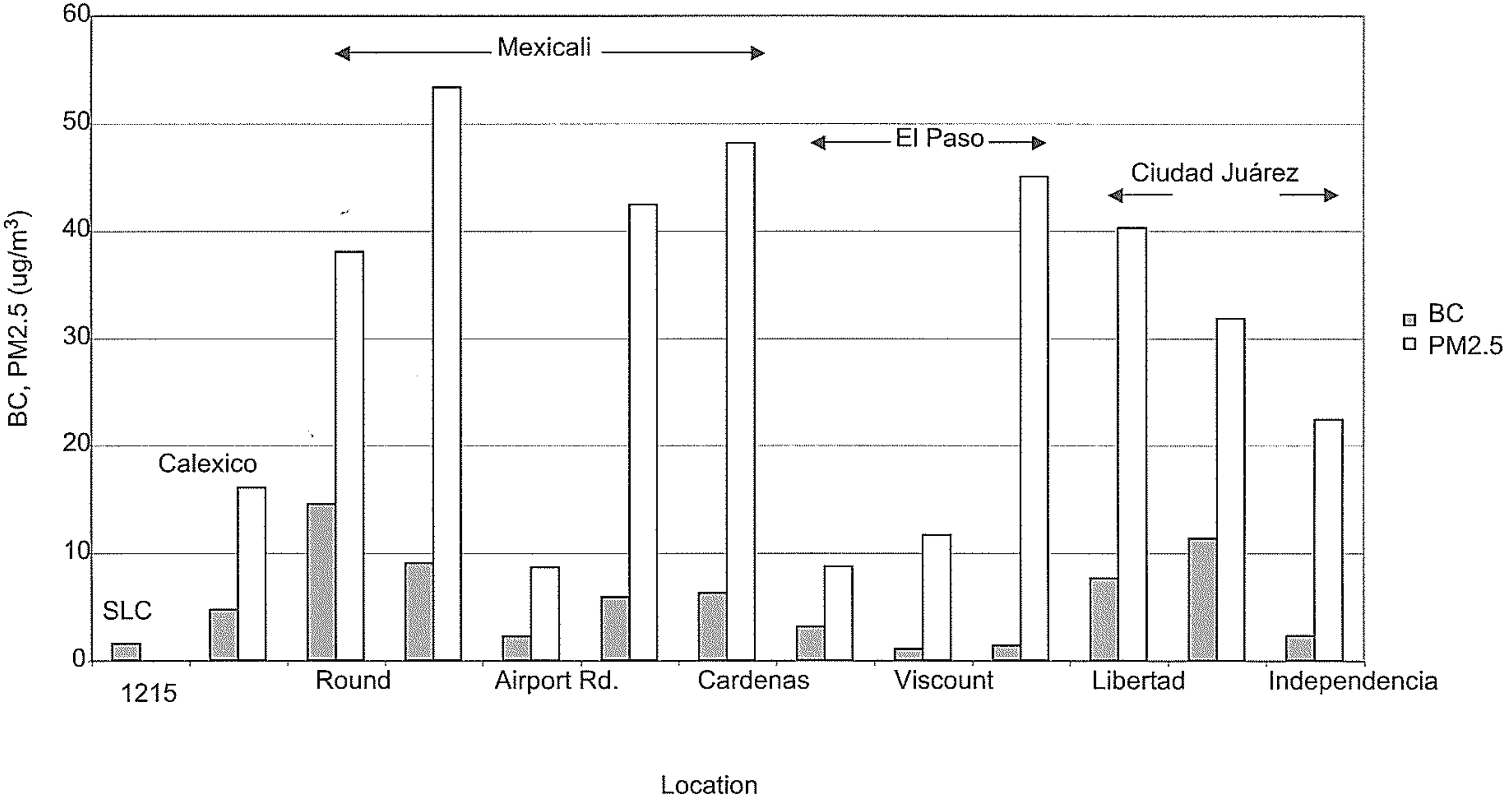

Figure 3. Black Carbon and PM2.5 Concentrations at Various Locations

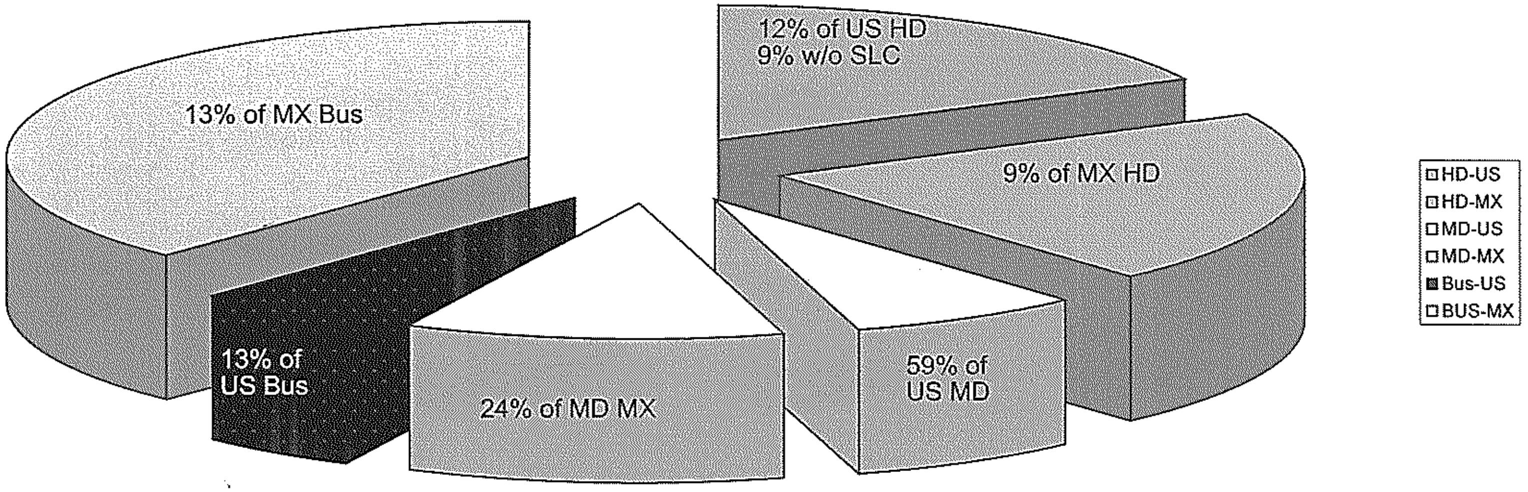

Figure 4. Breakdown of Emission Factors by Emission Vehicle Class. (The pecentages denote the portion of vehicles from the class and country with measurable emissions)

Table 1. Description of Sampling Locations

Name	Location	Traffic				Description
		Density	Speed (mph)	Acc/Dec[1]	Type[2]	
SR7	Calexico	Moderate	35	A	T	California State Road 7, where 18-wheelers cross into the U.S. from Mexico.
Round	Mexicali	Heavy	10-May	D	all	Round about in the city center.
Anahuac	Mexicali	Heavy	20	D	PV, B	Blvd. Anahuac y Lago de Los Esclavos.
Cárdenas	Mexicali	Heavy	20	A	all	Blvd. Lázaro Cárdenas y López Mateos
Carranza	Mexicali	Heavy	10-May	D	all	Blvd. V. Carranza y Blvd. L. Cárdenas.
Airport Rd.	Mexicali	Light	55	C	PV, T	A four-lane road on the outskirts of town.
Airway	El Paso	Moderate	40	C	PV, T	A six-lane road near the airport and several industrial parks.
Viscount	El Paso	Light	35	C	PV, B	A four-lane road.
CustX	El Paso	Moderate	20	A	T	A two-lane road near the entrance ramp of the freeway and just outside the U.S. Customs exit.
Libertad	Juárez	Heavy	10-May	C	PV, B	A two-lane road.
Independencia	Juárez	Moderate	50	C	All	A four-lane road on the outskirts of town.
Juan	Juárez	Heavy	40	A	All	A six-lane road, one of the main thoroughfares.
I-215	Salt Lake City	Heavy	40	A	All	The interstate on-ramp of I-215 located near the industrial side of town.

1 A – Acceleration; D – Deceleration; C – Constant speed.
2 T – truck; PV – passenger vehicle; B – bus.

Table 2. Vehicles with Measurable Emissions, Excluding Passenger Vehicles

		Heavy-Duty Vehicle[1]				MDV[1]		Bus[1]	
City	Location	U.S.	MX	Dual	Unk.	U.S.	MX	U.S.	MX
Calexico	SR7	3/14		3/14	0/1				
Mexicali	Round		2/77		0/27		4/23		5/139
Mexicali	Anahuac		1/31		0/4		2/6		8/44
Mexicali	Cardenas		2/23		0/1		1/8		7/18
Mexicali	Carranza	2/15	4/18		37665		3/9		3/15
Mexicali	Airport	1/12	2/24		13940		1/9		
El Paso	Airway	4/68			37635	2/5			
El Paso	Viscount	1/8				5/7		7/53	
El Paso	CustX	2/25	16/132		0/56				
Juárez	Independ		3/36				4/20		1/15
Juárez	Libertad						1/2		12/103
Juárez	Juan						4/8		18/75
SLC	I215	12/61				3/5			

MDV: medium duty vehicle; Dual: the vehicle has both a U.S. and Mexican license plate; Unk.: no license plate or unreadable plate.

[1] number of vehicles in the class and from the country that have measurable emissions/total number of vehicles in the class from the country.

Table 3. Maximum Emission Factors at Each Location

City	Location	Plate	Description	BC (g/kg)	PAH (mg/kg)	$PM_{2.5}$ (g/kg)
Calexico	SR7	CA	HDV	8.06	21.8	ND
Mexicali	Round	MX	PV	293	283	15.2
Mexicali	Mexicali	MX	Bus #664	77.1	18.9	29.6
Mexicali	Gardenas	MX	HDV	45	5.45	10.9
Mexicali	Caranza	MX	Bus	26	4.76	4.38
Mexicali	Coke	MX	Bus #18	0.52	0.41	0.33
El Paso	Airway	NM	HDV	16.3	7.9	5.9
El Paso	Viscount	TX	Bus	5.79	5.85	ND
El Paso	CustX	MX	HDV	15	5.83	8.6
C. Juárez	Independencia	MX	MDV	25.2	7.9	18.5
C. Juárez	Libertad	MX	Bus #2143	115	2.83	102
C. Juárez	Juan	MX	MDV	76.1	39.4	22.8
SLC	I-215	UT	HDV	4.99	4.81	ND

HDT: heavy duty vehicle; PV: passenger vehicle, MDV: medium duty vehicle.
Emission factors are per kg fuel.

Table 4. Average Emission Factors and Standard Deviations for Several Locations with High Levels of Bus and Heavy-duty Vehicle Traffic. (Emission factors are per kg fuel)

Location	Count	Country	BC (g/kg)	PAH (mg/kg)	$PM_{2.5}$ (g/kg)
Buses					
Libertad	13	MX	13.6±32.3	11.9±28.5	3.97±3.48
Anahuac	10	MX	11.5±3.39	2.48±0.650	4.59±2.00
Juan	10	MX	15.3±17.3	5.53±9.33	3.67±4.76
Viscount	7	U.S.	2.79±2.79	0.53±0.38	1.92±2.07
Heavy-DutyTrucks					
Airway	7	MX	3.97±6.09	2.15±2.11	2.85±2.94
CustX	12	MX	5.16±4.72	3.67±3.87	4.45±3.64
SR7	3	Dual	6.37±0.389	10.1±10.6	ND
CustX	2	U.S.	3.33±2.28	1.28±0.137	1.44±0.803
SR7	3	U.S.	4.06±3.46	10.4±9.96	ND
I-215	15	U.S.	1.73±1.83	1.17±1.04	ND

Table 5. Mexicali Vehicle Fleet

Classification	Vehicle count	%	km/vehicle/ day	Annual km
Private cars	168,160	68.83	45	16,470
Taxis	1,105	0.45	100	36,600
Pick up trucks	46,005	19.1	70	25,620
Motorcycles	951	0.39	70	25,620
Passenger vehicles	216,221	89	51	18,560
Light duty trucks	6,710	2.78	70	25,620
Gasoline passenger buses	802	0.33	185	67,710
Diesel passenger buses	258	0.1	185	67,710
Buses	1060	0.43	185	67,710
Gasoline heavy-duty trucks	6,939	2.88	100	36,600
Diesel heavy-duty trucks	9,880	4.14	80	29,280
Heavy-duty vehicles	16,819	7	88.3	32,300
Total	**240,810**	**100**	**905**	**331,230**