On-Road Measurement of Automotive Particle Emission Factors by Ultraviolet Lidar and Transmissometer

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1. Introduction

DRI has developed a remote sensing method for measuring particulate matter (PM) emissions from on-road, in-use, spark ignition and diesel vehicles. Remote sensing of gaseous pollutants in vehicle exhaust is a well-established, economical way to determine on-road emissions for thousands of vehicles per day.

The DRI Vehicle Emissions Remote Sensing System (VERSS) combines a 266-nm ultraviolet lidar and transmissometer with a commercial remote sensing device (RSD) to measure both particulate matter and gaseous pollutants in the exhaust of passing vehicles. The lidar and transmissometer ultraviolet wavelength achieves greater sensitivity to sub-micrometer particles, where the greatest mass fraction has been reported. The VERSS system integrates the lidar backscatter with infrared column mass density CO_2 measurements to estimate fuel-based PM emissions. Carbon monoxide (CO), nitric oxide (N0), and hydrocarbons (HC) are measured by the collocated gaseous remote sensing.

Ancillary measurement of speed and acceleration and the acquisition of a picture of the rear plate of each vehicle permits stratification of the vehicle emissions by model year, fuel type, vehicle type and vehicle specific power. Example data shown here are from a large field experiment conducted in Las Vegas, NV during spring and summer 2001 and 2002. The data analysis revealed that the dirtiest 10% of the entire measured mobile fleet (14815 valid lidar measurement) was responsible for more than 80% of the total PM emitted.

2. Vehicle emission factors (EF) are calculated from CO_2 and PM column contents, as grams of PM emitted per kilograms of fuel consumed.

Assumptions:

•Spherical particle shape

-Density: 1.25 g cm^{-3}

-Index of Refraction:

Organic Carbon $m = 1.5$

Elemental Carbon $m = 1.5 – i0.5$

•Particle composition

-Solid OC for spark ignition

-Layered sphere with EC core and OC shell for Diesel

•Mass size distributions approximated as lognormal:

-mass median diameter 0.15 µm

-geometric standard deviation 1.5 µm

•UV Transmissivity near 1

•Fuel Composition:

- Gasoline $C_nH_{1.825n}$

- Diesel C_nH_{2n}

Measurements:

•PM UV backscattering

•PM UV transmission

•CO_2 column mass density ρ_{CO2}

•Lidar calibration with CO_2 and HEPA filtered air

Mass Backscattering Efficiencies

Theoretically calculated from the assumptions:

•Spark ignition: $E_{bscat} = 0.16$ m^2/g·sr

•Diesel: $E_{bscat} = 0.08$ m^2/g·sr

Mass Extinction Efficiencies

Theoretically calculated from the assumptions:

•Spark ignition: $E_{ext} = 10$ m^2/g

•Diesel: $E_{ext} = 13$ m^2/g

EF Computation:

•PM mass density column density from backscattering:

ρ_{PM} = (Exhaust Backscattering) / E_{bscat}

•PM mass density column density from transmission:

ρ_{PM} = (Exhaust Optical Depth) / E_{ext}

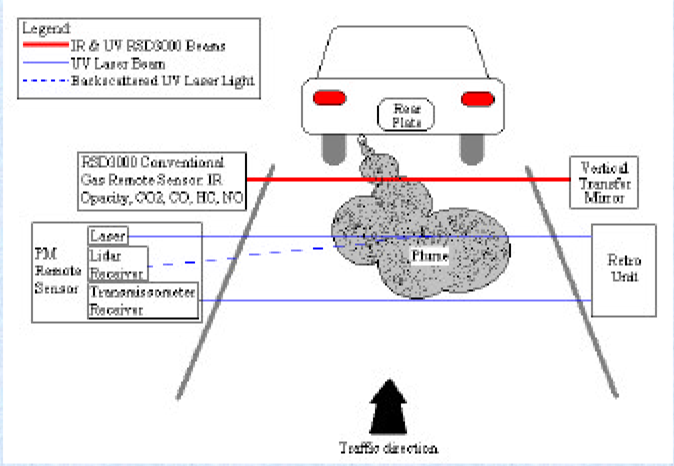
•Emission factors:

$$EF_{PM} = (CMF_{fuel}/CMF_{CO2})(\rho_{PM}/\rho_{CO2}) \quad [grams_{PM}/kg_{fuel}]$$

Where CMF = Carbon mass fraction

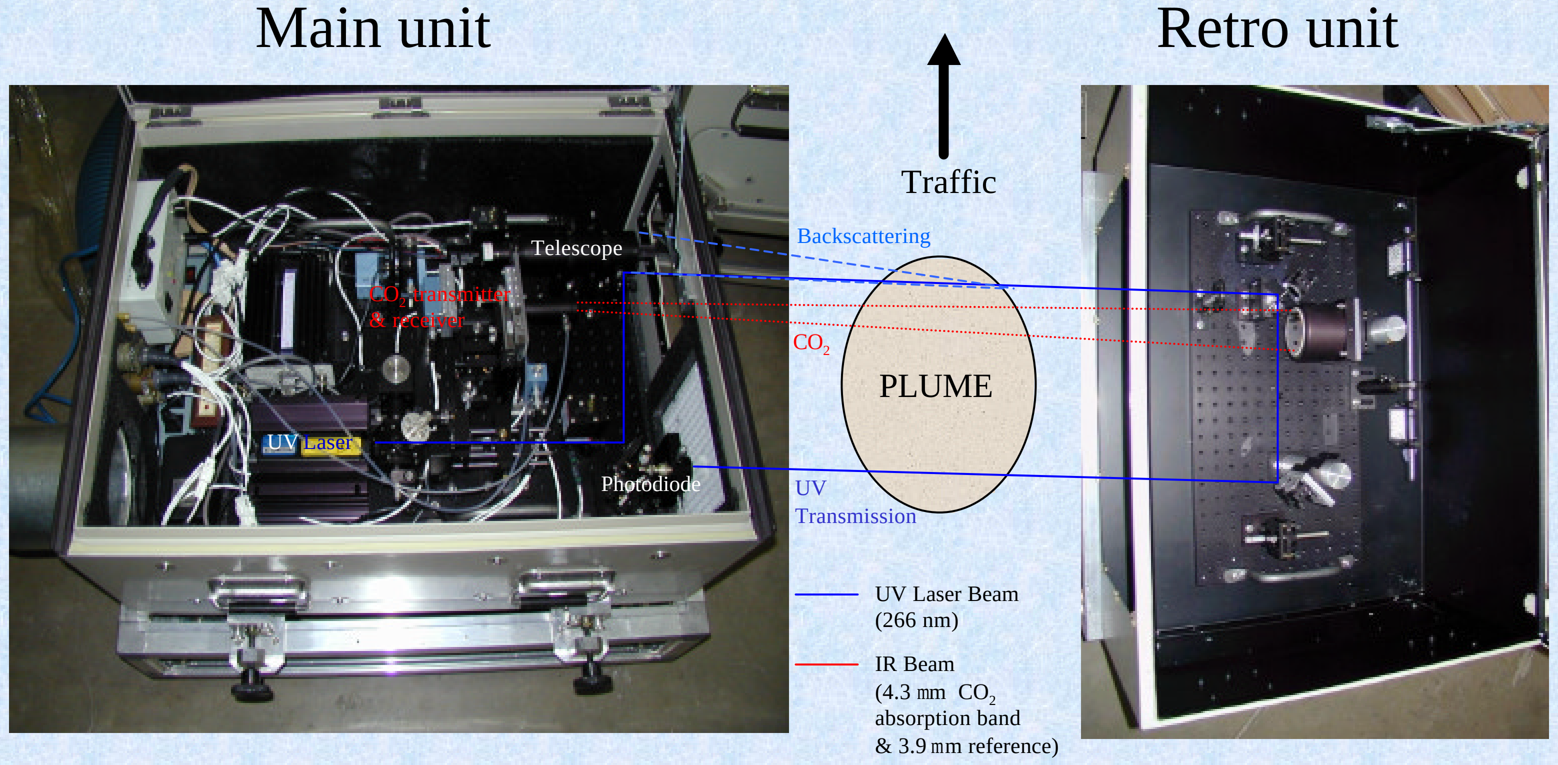
3. UV Lidar and Transmissometer

On-Road setup



Main unit

Retro unit



4. Results

An example of a Diesel vehicle (ISUZU, model year 2000, CO EF=1.3 g_{CO}/kg_{fuel}, HC EF=2.5 g_{HC}/kg_{fuel}, NO EF=20 g_{NO}/kg_{fuel}) is presented below.

Panel (a): time evolution of PM and CO_2 column mass density, panel (b): linear regression.The slope between the PM column mass density and the consumed fuel column mass density corresponds to the emission factor:

PM EF=1.47 g_{PM}/kg_{fuel}

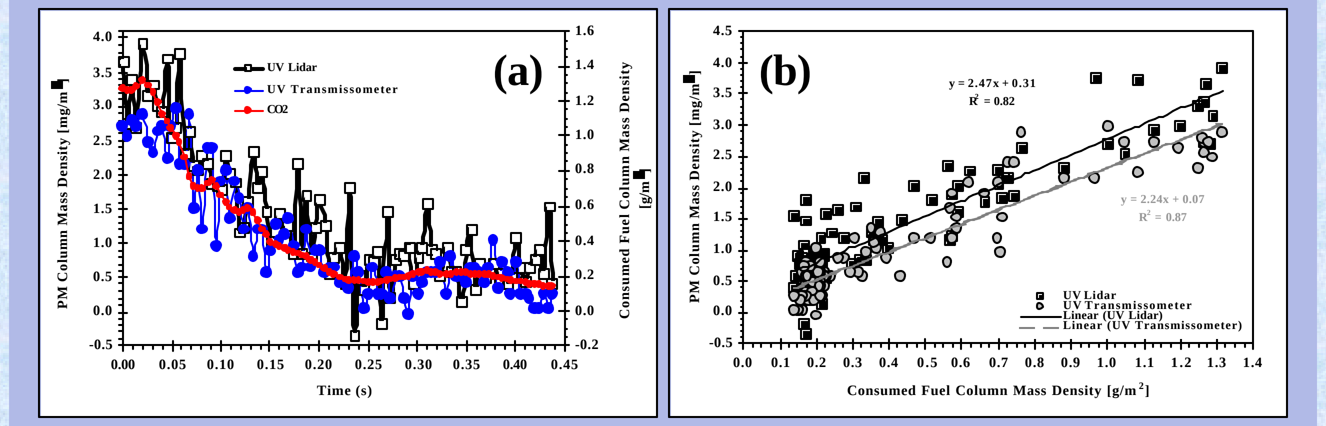
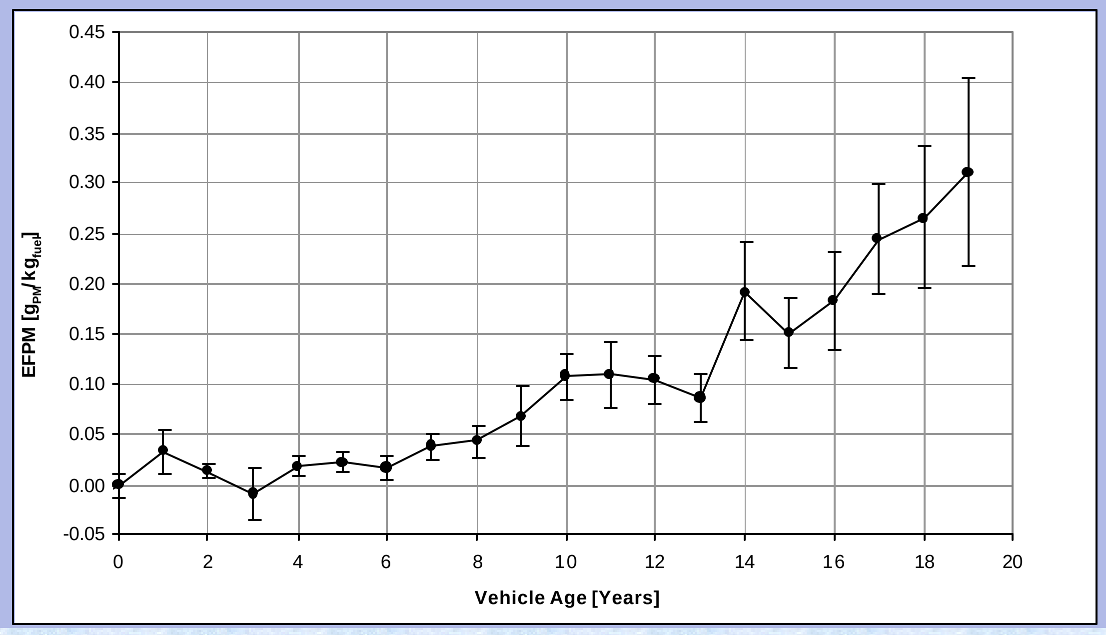


Table: Average PM emission factors for Diesel and spark ignition vehicles.

Year	Engine	Average $[g_{PM}/kg_{Fuel}]$	Standard Error $[g_{PM}/kg_{Fuel}]$	# Vehicles
2001	***Spark ignition***	0.070	0.007	6047
	Diesel	2.1	0.35	65
2002	***Spark ignition***	0.047	0.004	8768
	Diesel	1.3	0.2	191



Plot of PM emission factors for spark ignition vehicle versus age.

5. References

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3. Kuhns, H. D.; Mazzoleni, C.; Moosmüller, H.; Nicolic, D.; Keislar, R. E.; Barber, P. W.; Li, Z.; Etyemezian, V.; Watson, J. G. **"Remote Sensing of PM, NO, CO, and HCEemission Factors for On-Road Gasoline and Diesel Engine Vehicles in Las Vegas, NV"**, *Sci. Total. Environ.* 2003, in press.
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