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Individual Measurements of the Emission Factor of Aerosol Black Carbon in Automobile Plumes

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As automobiles passed a measuring point, we recorded the concentrations of carbon dioxide and aerosol black carbon (BC) in their dispersing exhaust plumes. After subtraction of background levels, the ratio of the increments of these species allows us to calculate the emission factor of BC per unit mass of fuel from each individual vehicle. These factors spanned a range of greater than two orders of magnitude, representing the emission of from 4×10^{-6} to 10^{-3} grams of aerosol black carbon per gram of carbon consumed in the fuel. Their distribution showed that 20 percent of the vehicles accounted for 65 percent of the emissions. The real-time measurement methodology allows for a determination of the distribution of emission factors across the actual population of sources. These results are similar to the wide range of carbon monoxide emission factors reported recently.

The combustion of hydrocarbon fuels results in the release to the atmosphere of major and minor effluent species. The major species are water vapor and carbon dioxide, normally accounting for more than 90 percent of the carbon and hydrogen atoms in the fuel. Depending on combustion conditions, carbon monoxide and nitrogen oxides may also be emitted at a level of a few percent. For present purposes, it is sufficient to note that the rate of emission of carbon as carbon dioxide is generally greater than 90 percent of the rate of consumption of carbon in the fuel. Minor effluent species include organics, any trace elements that may have been present in the fuel or contributed by the combustor, and particulate matter. One ubiquitous component of this last category is aerosol "black" carbon (BC), sometimes referred to as "elemental" carbon (EC).[1,2,3] This material is strongly optically absorbing due to its graphitic microcrystalline structure;[4] in most environments, it is the dominant optically absorbing aerosol species, and its presence in urban and regional atmospheres contributes to visibility extinction.[5,6]

For the purposes of this paper, we define the "fuel-specific emission factor" for BC as the mass of carbon emitted in a graphitized aerosol form divided by the mass of carbon consumed in the fuel. This factor is highly variable, depending on the fuel, the combustion conditions, and the level of technology of the combustor. Emission factors for common sources expressed as grams of aerosol BC emitted per gram of fuel carbon consumed range from 10^{-2} (e.g. a poorly running diesel engine) to less than 10^{-6} (e.g. a well controlled industrial-scale gas boiler).[7] Thus, a natural gas fired steam generator rated at 50 million Btu/hr may emit less aerosol black carbon in one day than a diesel truck driven for one mile. Such a large variation in emission rates suggests that emission models should consider these ranges in their estimates of the degree of accuracy of predicted releases to the atmosphere from various classes of sources. In this paper, we present preliminary results from a study of the BC emissions from an indigenous (i.e. non-selected) population of automobiles, with each vehicle being measured independently. The objective of the study was to examine the distribution of BC emission factors for these real-world vehicles operating under realistic on-road conditions.

Similar work has been performed for the measurement of carbon monoxide from individual vehicles passing an observation point.[8,9] Those results showed that there was a very wide range of CO emission factors for a real-world population of vehicles operating under realistic conditions, and that a small fraction of the number of vehicles accounted for the great majority of CO emissions. These findings are in accord with our work on black carbon emissions, as will be shown.

Implications

This research demonstrates that a small fraction of automobiles contribute the majority of emissions of aerosol "black" carbon. This pollutant contributes to visibility degradation, may alter atmospheric chemistry, and may have a public health impact. Its regulation and abatement are desirable goals of public policy that may lead to proposals for the routine testing of this emission. Our work shows that some vehicles emit a thousand times more aerosol carbon than others. To achieve effective results, this testing will have to cover as broad a spectrum of vehicles as possible: gasoline and diesel, old and new, registered and unregistered.

Measurement Approach

We calculate the aerosol black carbon emission factor for individual vehicles by measuring the concentrations of carbon dioxide and BC in the plume of the vehicle after it passes the measurement point. The sampling location was on an uphill grade of approximately 10 percent on a two-lane road with a traffic density of less than 100 vehicles per hour. As the results showed, we were able to measure the exhaust plumes of individual vehicles with good resolution.

Designate the fuel consumption rate of carbon as $[C_F]$ grams per second, and the tailpipe emission rates of carbon in the forms of carbon dioxide, aerosol black carbon, and all other carbon-containing species as $[CO_2]$, [BC], and $[C_O]$