The Kansas City Light-Duty Vehicle Emission Study

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Mobile sources significantly contribute to ambient concentrations of particulate matter, criteria gases, and air toxics. The United States Environmental Protection Agency (EPA), the Coordinating Research Council (CRC), the Department of Energy (DOE) National Renewable Energy Laboratory (NREL), the Department of Transportation (DOT), and the Emission Inventory Improvement Program (EIIP) have initiated a program to evaluate exhaust emissions from light-duty, gasoline powered vehicles in the Kansas City Metropolitan Area. The program consists of measuring $PM_{2.5}$, air toxics, and criteria gases in exhaust emissions of up to 480 randomly selected, light-duty motor vehicles using a portable chassis dynamometer. Continuous $PM_{2.5}$, HC, CO, and NOx; integrated $PM_{2.5}$, VOC, and aldehyde; fuel; and lubricating oil samples will be collected for each vehicle. A select number of vehicle samples will be analytically speciated for PM (metals, EC/OC, ions, and SVOCs), VOCs, and aldehydes. In addition, a select number of vehicles will be outfitted with on-board emissions and activity monitors to compare criteria gas emissions from chassis dynamometer testing using a specified urban driving cycle with real world driving. The results from the study will be used to improve mobile source inventories, develop emission profiles for source apportionment studies, and enhance future emissions and exposure models. This presentation provides details on the project with an emphasis on applicability to the development of improved emission inventories.

Introduction

Mobile sources significantly contribute to ambient concentrations of airborne particulate matter. Recent source apportionment studies for PM_{10} and $PM_{2.5}$ indicate that mobile sources can be responsible for over half of the ambient PM measured in an urban area (Motallebi, 1999; Magliano, 1998; Dzubay, 1988). Some of these source apportionment studies have attempted to differentiate between contributions from gasoline and diesel combustion. Studies conducted in Denver and Phoenix indicated that gasoline combustion from mobile sources contributed more to ambient PM than diesel combustion (Lawson, 1998; Ramadan, 2000). However, studies conducted in Los Angeles and the San Joaquin Valley in California indicate that diesel combustion contributed more than gasoline combustion to ambient PM (Schauer, 1996; Schauer, 2000). Existing emission inventories developed by the U.S. Environmental Protection Agency (EPA) also suggest diesels contribute more than gasoline vehicles to ambient PM concentrations.

Exhaust emissions of particulate matter from gasoline-powered motor vehicles have changed significantly over the past 25 years (Cadle et al., 1999). These changes have resulted from reformulation of fuels, the wide application of exhaust gas treatment, and changes in engine design and operation. Because of these evolving tailpipe emissions, along with the wide variability of emissions between vehicles of the same class (Hildemann et al., 1991; Cadle et al.,

1997; Sagebiel et al., 1997), well-defined average emissions profiles for the major classes of motor vehicles have not been established.

The majority of PM emitted by motor vehicles is in the $PM_{2.5}$ size range. Kleeman et al. (2000) has shown that gasoline and diesel fueled vehicles produce particles that are mostly less than 2.0 µm in diameter. Cadle et al. (1999) found that 91% of PM emitted by in-use gasoline vehicles in the Denver area was in the $PM_{2.5}$ size range, which increased to 97% for "smokers" (i.e., light-duty vehicles with visible smoke emitted from their tailpipes). Durbin et al. (1999) found that 92% of the PM was smaller than 2.5 µm for smokers. The mass median diameter of the PM emitted by the gasoline vehicles sampled by Cadle et al. (1999) was about 0.12 µm, which increased to 0.18 µm for smokers. Corresponding average emissions rates of $PM_{2.5}$ were 38 mg/mi for normal emitting gasoline vehicles and 222 mg/mi for gasoline smokers.

Emissions from smokers are comparable to those from diesel vehicles. Thus, older and poorly maintained gasoline vehicles could be significant sources of $PM_{2.5}$ (Sagebiel et al., 1997; Lawson and Smith, 1998). Durbin et al. (1999) point out that although smokers constitute only 1.1 to 1.7% of the light-duty fleet in the South Coast Air Quality Management District in California, they contribute roughly 20% of the total PM emissions from the light-duty fleet. Motor vehicles that are high emitters of hydrocarbons and carbon monoxide can be high emitters of PM (Sagebiel et al.,1997; Cadle et al., 1997). National distributions of smokers and high emitting vehicles for PM have not been evaluated.

A major obstacle in previous emissions testing studies has been the recruitment of vehicles. Most studies have not incorporated random sampling in the study design due to the high non-participation rate and the high incentive costs associated with random sampling of vehicles. Therefore, few studies, and no studies evaluating light-duty PM emissions, can be used to represent the distribution of vehicle emissions in a large population.

The U.S. Environmental Protection Agency's (EPA) Office of Transportation and Air Quality (OTAQ), in cooperation with the EPA Office of Research and Development (ORD); the Coordinating Research Council (CRC); the U.S. Department of Transportation (DOT); the U.S. Department of Energy (DOE); and state and local air pollution control agencies (STAPPA/ALAPCO), plans to conduct a program to evaluate the distribution of particulate matter (PM) exhaust emissions from light-duty gasoline vehicles. Data obtained from this program will be used to evaluate and update existing and future mobile source emission models (MOBILE6 and MOVES), evaluate existing emission inventories and recent source apportionment studies comparing the contribution of gasoline and diesel combustion to ambient PM concentrations, and assess the representativeness of previous PM emissions studies.

Methods

The U.S. Environmental Protection Agency (EPA) proposes to conduct exhaust emissions testing on 480 light-duty, gasoline vehicles randomly selected from the Kansas City Metropolitan Area. The goal of the project is to determine the distribution of PM emissions in a randomly selected fleet as well as identify the percent of high emitters in the fleet. The primary focus areas of the project include vehicle recruitment, vehicle testing, and sample analysis.

Vehicle Recruitment Vehicle recruitment activities were designed to identify the distribution of PM emissions from gasoline vehicles in order to better evaluate the contribution of gasoline high emitters to ambient PM concentrations. Vehicles will be randomly chosen and recruited from the Kansas City Metropolitan Area (KCMA) using random digit dialing with a comparison to the Kansas and Missouri registration databases. After the initial recruitment and identification of volunteers, an assessment of non-respondents to the original program will be conducted to ensure that emissions from participants' vehicles are representative of the Kansas City and national fleets.

Table 1 shows the number of vehicles to be tested for the program. Testing strata were developed based on the type and year of the vehicle. These strata represent different technology classes of vehicles. The number of vehicles chosen for sampling in each strata were based on the variability of emissions from similar technology vehicles tested in studies in Denver, Colorado and Riverside, California.

Table 1. Estimated Sample Sizes by Stratum to Achieve Data Precision Goals

Stratum (h)	Vehicle Class	Age Class	Sample size (n_h)[1]
1	Truck	Pre 1980	50
2	Truck	1980-1990	140
3	Truck	1991 and newer	70
4	Car	Pre 1980	40
5	Car	1980-1990	50
6	Car	1991 and newer	130
Total			480

1 Half of each sample to be collected during the summer round, and the remaining half during the winter round.

Vehicle Testing. All vehicle testing will occur outdoors under ambient conditions. Each vehicle will be conditioned prior to testing to insure any carbon buildup in the exhaust system is removed. Vehicle conditioning will occur by driving the vehicle on a pre-established route in the vicinity of the testing location. The conditioning route will contain multiple high speed accelerations, continuous high speed operation, and low speed operation and idling just prior to the completion of the conditioning route. After conditioning, the vehicle shall sit overnight prior to emissions testing on the dynamometer.

To the extent feasible, vehicles will be tested in an order anticipated to be from lowest PM emissions to highest PM emissions for each day. The general order is for vehicles from stratum 6, 3, 5, 2, 4, and 1 as indicated in Table 1.

Vehicle exhaust emissions testing will occur using the EPA ORD portable chassis dynamometer. The EPA dynamometer simulates driving on a Clayton Model CTE-50-0

chassis dynamometer. The dynamometer is capable of simulating a continuous spectrum of loads from three to 50 Hp @ 50 mph and inertias from 1750 to 3000 pounds in 250 pound increments and 3000 to 5500 pounds in 500 pound increments. Cooling fluid for the dynamometer's water brake power absorption unit consists of a 50/50 mixture of water and glycol. The fluid is recirculated and cooled by a self-contained pumping and cooling system.

Vehicles will be operated over the LA92 Unified Driving Cycle (shown in Figure 1). The LA92 cycle consists of a cold start Phase 1, a stabilized Phase 2, a 600-second engine off soak, a warm start Phase 3. PM filter collection will occur separately for each phase to minimize potential loss of the volatile fraction of PM during hot, stabilized operating conditions.

A positive displacement pump-constant volume sampling (PDP-CVS) system will be used to quantitatively dilute exhaust gas from the vehicle operating on the dynamometer. The PDP-CVS system is constructed of an 8-inch diameter stainless steel dilution tunnel and a SutorBilt Model GAELAPA (6-LP) PDP operating at 500 CFM. Dilution air is treated with a charcoal bed (for HC stabilization) followed by a HEPA filter (99.97% DOP filter efficiency) to remove particles prior to mixing with vehicle exhaust. The tunnel operating temperature will be maintained at approximately 110°F for all testing analyses.

Fuel and oil samples will be collected from all vehicles after completion of the dynamometer test(s). Fuel samples will also be collected from local gasoline distributors to account for newer vehicles in which fuel samples cannot be collected.

Five percent of the vehicles tested for this program will be randomly selected for replicate emissions testing. A higher percentage of vehicles recruited at the beginning of the program may be selected for replicate testing to insure that five percent is an adequate number of vehicles. After the initial test, the selected vehicle shall repeat a 600-second engine off soak, a warm start Phase 3, and a stabilized Phase 4.

Two round-robin tests will be conducted for the program: a pilot test and the field testing in Kansas City. For the pilot testing, comparisons will be made between the dynamometer in Kansas City and the EPA laboratory dynamometers in Ann Arbor, MI. Three EPA vehicles will be tested at the Ann Arbor labs and shipped to Kansas City for testing on the portable dynamometer. A canister of fuel will also be transported with the vehicle to insure testing under similar operating conditions. After replicate testing in Kansas City, the vehicle shall be returned to Ann Arbor for a third suite of tests.

Twenty-five vehicles tested during Round 1 of the program will be re-tested during Round 2 to determine comparability between testing events. These vehicles will be randomly selected from each strata as shown in Table 2. This data may also provide information on the effect of ambient temperature on PM emissions.

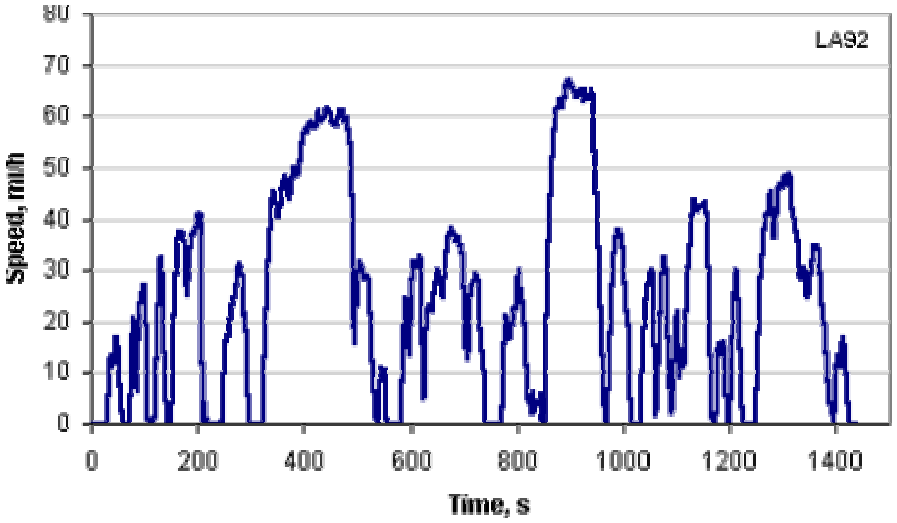

Figure 1. LA92 driving cycle time trace.

Table 2. Estimated Sample Sizes by Stratum for Round 2 Re-Testing

Stratum (h)	Vehicle Class	Age Class	Sample size (n_h)[1]
1	Truck	Pre 1980	3
2	Truck	1980-1990	7
3	Truck	1991 and newer	3
4	Car	Pre 1980	3
5	Car	1980-1990	3
6	Car	1991 and newer	6
Total			25

1 Number of randomly selected vehicles tested during Round 1 re-tested during Round 2.

Sample Collection and Analysis. Measurement methods to be used in this project include continuous monitoring and integrated sample collection. Continuous methods for measurement of fine particulate mass provide several useful data products as well as immediate feedback about the nature of the emissions from vehicles. These methods are ideally suited to identify the portions of a driving cycle where particulate emissions are greatest and least. Rapid time response is also useful for the successful deployment of dilution tunnels to provide knowledge of the state of the tunnel. For example, these instruments are useful in determining if a tunnel has been adequately conditioned between measurements. The integrated measurements allow for detailed analysis of chemical components present in the vehicle's exhaust for which no continuous methods exist.

Samples will be collected from the dilution tunnel through an isokinetic probe> For PM sampling, the sampling train will consist of a particle size limiting cyclone, filter cassette, and flow control system. In addition to the integral filter measurement, a continuous exhaust aerosol mass measurement system (Quartz Crystal Microbalance (QCM), Booker Systems Ltd.) will be used to provide second by second measurement of exhaust aerosol mass concentrations. This unit will share sample with the integral filter system.

The sampling probe is custom made to match the flow velocity of the dilution tunnel to that of the 2.5 um cyclone. The probe is constructed with a knife edge orifice to reduce sampling turbulence. The cyclone and filter cassette (University Research Glassware, Chapel Hill, NC) are constructed of stainless steel. The sampling train is designed to collect particles having a mass median diameter (MMD) of less than 2.5um. Flows are controlled with a mass flow controller @ 16.7 lpm for PM samples collected on 47-mm Teflo^{TM} (2.0 um pore size) Teflon membrane filters (Pall-Gelman, Ann Arbor, Michigan). Additional filters will also be collected for PM chemical speciation including metals, semi-volatile organic compounds, ions, and elemental/organic carbon. A number of filter blanks will be evaluated to insure quality control. Laboratory control blanks, transport and handling blanks, and field blanks will be included

In addition to PM collection, total hydrocarbons (THC) will be analyzed with a Horiba model 236-Heated Flame Ionization Detector (HFID). Background THC will be monitored with a second HFID, a Horiba model FIA 34A. Oxides of nitrogen (NOx) will be analyzed with a Horiba Model CLA-220 Chemiluminescent instrument. Carbon monoxide and carbon dioxide will be analyzed with Horiba Model AIA-210/220 infrared (IR) instruments. A third IR instrument, a Horiba model AIA23-AS, will be used for analysis of low (< 1000 PPM) carbon monoxide concentrations. All six instruments are rack mounted and plumbed for introduction of zero, span, and sample gases through the use of solenoid valves and pushbutton controls. Integrated gaseous measurements will be conducted for volatile organic compounds (VOCs), including benzene, toluene, xylenes, and 1,3-butadiene, and aldehydes/ketones. A number of gaseous blanks will also be evaluated to insure quality control.

Conclusions

The EPA and a consortium representing other federal, state and local governments and the vehicle, engine, and fuel industry have joined to conduct a vehicle emission assessment program in the Kansas City metropolitan area. The goal of this project is to provide to the scientific community more accurate emissions data from in-use vehicles that can be used to model emissions on a national scale. The impact of the study will have significant influence on national policies to improve air quality across the nation, as evident by number of public and private sector organizations providing funds and expertise to the study.

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