Comparing Three Approaches of Estimating Bus Self-Pollution - A Pilot Study

Extended Abstract #313

Whitney L. Webber, Mark Davey, Timothy Larson*, and L.-J. Sally Liu
Department of Environmental and Occupational Health Sciences, *Department of Civil
and Environmental Engineering, University of Washington, Seattle, WA  98105

Douglas R. Lawson
National Renewable Energy Laboratory, Golden, CO  80401-3393

Robert G. Ireson
Air Quality Management Consulting, Greenbrae, CA  94904

Barbara Zielinska
Atmospheric Sciences Division, Desert Research Institute, Reno, NV  89512-1095

Charles A. Lapin
Lapin & Associates, Glendale, CA  91208

Michael Easter
California EnSIGHT, Walnut Creek, CA  94596

Thomas W. Hesterberg
International Truck and Engine Corporation, Warrenville, IL  60555

INTRODUCTION

Retrofitting diesel engines in school buses to reduce children’s diesel exhaust exposures
is the focus of many regulatory initiatives.  In order to determine whether such diesel
retrofit technologies are effective in reducing the exposure to student passengers, it is
necessary to differentiate the contribution of a bus's own emissions (or self-pollution) to
on-bus air pollution levels from other sources such as on-road vehicle exhaust and
background air pollution levels.  Recent developments in the literature have suggested
several potentially viable methods for differentiating self-pollution from other on-road
sources of particulate matter.1-4  These methods include: 1) using fuel-borne iridium (Ir)
as a tracer for diesel exhaust particulate (DEP) from the bus itself; 2) using a lead-vehicle
approach to account for other sources of on-road particulate matter; and 3) using source
apportionment methods to quantify self-pollution.  Findings from Ireson et al. (2003)
provided preliminary evidence of the sensitivity and specificity of the iridium tracer
method over other methods.  Recent work2 also suggests the possibility that PM
emissions from the crankcase vent on school buses may contribute to in-cabin PM.  To
address this possibility, we developed a new method in this study that uses a deuterated
alkane tracer in engine lubricating oil.
An advantage of the lead vehicle approach and source apportionment is that they are neither as expensive nor labor intensive as the tracer methods; thus, they can be easily implemented and provide some additional context for assessing the implications of tracer results. However, a potential drawback of these two methods is that they do not permit direct identification of the bus’s own emissions. Therefore, we conducted a study to compare these three approaches to determine a bus’s self-pollution.

METHODS

The intensive monitoring campaign was conducted in August-September 2005 on two representative Seattle school buses, including a 2000 retrofit bus and a 2003 non-retrofit bus. The study buses were operated along a residential bus loop, simulating typical pick-up stops for the to-school route and drop-off stops for the back-home route. Each route took one hour with the two routes forming the loop of each bus run. Each bus was monitored in two phases. The first phase involved two consecutive days (two runs per day with windows open or closed) of on-bus (low-level) monitoring. A lead vehicle, a 1996 Chrysler Minivan with windows open, was driven ahead of the bus during all low-level sampling runs to monitor on-road traffic exhaust. The second phase of the study entailed source sampling while the bus was operated on the same bus loop as used for the low-level runs. Prior to monitoring, the ultra-low sulfur diesel fuel and the lubricating oil were spiked with two tracers: iridium (Ir) and N-hexatriacontane-D74, respectively.

During the low-level sampling, both continuous and integrated monitors measured levels of PM$_{2.5}$, PM$_1$, ultrafine PM, PAHs, EC/OC, BC, CO, and NO$_2$ inside the bus and on the lead car. The integrated samplers included Harvard personal environmental monitors (HPEMs) sampling for PM$_{2.5}$ at 4 LPM with Teflon® (HPT) and quartz (HPQ) filters, active SKC TEA tubes (TEA) operated at 200 cc/min for NO$_2$, active personal DataRAMs with a PM$_{2.5}$-cut cyclone (4 LPM) and a filter cassette containing a quartz filter (pDQ) or Teflon filter (pDR), UMd PM$_{2.5}$/Ir impactors (120 LPM), and collocated PM$_1$ samplers (both with a Teflon® filter operating at 16.7 LPM). Seven continuous instruments recorded one-minute average air concentrations: active personal DataRAM (pDR), DUSTTRAK, Eco-Chem PAS2000CE monitor, P-Trak, HOBO data logger, aethalometer, and photoacoustic device.

The source sampling involved using an on-board dilution tunnel to collect PM$_1$ and PM$_{2.5}$ samples from the tailpipe and the crankcase, respectively, of each bus. The source sampling consisted of roughly three 30-minute runs for tailpipe emissions, followed by 20-minute runs for crankcase emissions. These source samples were analyzed for mass, iridium, selected elements, PAHs, hopanes, steranes, nitro PAH, and alkanes, including the deuterated tracer.

RESULTS

The average PM$_{2.5}$ concentrations ranged from 10.4 µg/m$^3$ to 14.8 µg/m$^3$ on Bus 1, 9.4 µg/m$^3$ to 28.4 µg/m$^3$ on Bus 2, and 5.1 µg/m$^3$ to 35.1 µg/m$^3$ on the lead vehicle (Table 1).
The collocated mean PM$_1$ levels ranged from 8.1 µg/m$^3$ to 19.3 µg/m$^3$, 5.6 µg/m$^3$ to 28.5 µg/m$^3$, and 3.9 µg/m$^3$ to 9.3 µg/m$^3$ on Bus 1, Bus 2, and the lead vehicle, respectively. Particle-bound PAHs, black carbon, and ultrafine PM as measured by the EcoChem, photacoustic instrument, and P-Trak, respectively, showed slightly elevated levels on the buses with windows closed than with windows open. With windows closed, mean concentrations of PM$_1$, black carbon, and ultrafine particles were higher on the bus than the lead vehicle by 8.3 µg/m$^3$, 1 µg/m$^3$, and 16,594 particles/cm$^3$, respectively.

PM$_1$, black carbon, and ultrafine particles were higher on the bus than on the lead vehicle, implying a contribution from the bus itself in addition to the background and traffic exhaust from other on-road vehicles. The differences between the bus and lead vehicle for these pollutants were less pronounced when windows were open on the bus. In contrast, PM$_{2.5}$ and particle-bound PAHs were higher on the lead vehicle than the bus, with greater differences observed when windows were open.

Table 1. Mean pollutant concentrations by vehicle type (bus and the lead vehicle) and window configuration (WC: windows closed, WO: windows open). Measurements on the lead vehicle (LV) were summarized based on the bus window configuration.

<table>
<thead>
<tr>
<th>Vehicle &amp; Window Configuration</th>
<th>PM$_1$ (µg/m$^3$)</th>
<th>PM$_{2.5}$ (µg/m$^3$)</th>
<th>Black Carbon* (ng/m$^3$)</th>
<th>Particle-bound PAHs (ng/m$^3$)</th>
<th>Ultrafine PM* (particles/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus – WC</td>
<td>14.7</td>
<td>15.8</td>
<td>1,824</td>
<td>74</td>
<td>27,288</td>
</tr>
<tr>
<td>Bus – WO</td>
<td>6.5</td>
<td>12.7</td>
<td>670</td>
<td>70</td>
<td>23,011</td>
</tr>
<tr>
<td>LV – Bus WC</td>
<td>6.4</td>
<td>15.9</td>
<td>817</td>
<td>130</td>
<td>10,694</td>
</tr>
<tr>
<td>LV – Bus WO</td>
<td>6.1</td>
<td>20.1</td>
<td>666</td>
<td>131</td>
<td>12,220</td>
</tr>
</tbody>
</table>

*For Bus 2 only.

Results from this "lead-vehicle approach" will be compared with those from the tracer and the chemical mass balance methods. The tracer method determines bus self-pollution, assuming that on-bus self-pollution comes from two major sources (tailpipe and the road draft tube of the crankcase). Assuming that Ir in crankcase emissions is negligible and the alkane tracer in tailpipe emissions is also negligible, we have:

$$\text{DEP}_{\text{self-pollution}} = \text{DEP}_{\text{tailpipe}} + \text{DEP}_{\text{crankcase}}$$

$$= \text{Ir}_{\text{on-bus}} * \frac{\text{DEP}_{\text{tailpipe}}}{\text{Ir}_{\text{tailpipe}}} + d-n-\text{alkane}_{\text{on-bus}} * \frac{\text{DEP}_{\text{crankcase}}}{d-n-\text{alkane}_{\text{crankcase}}}$$

The dual tracer method estimates the on-bus DEP concentrations attributable to the bus’s exhaust and crankcase emissions based on observed concentration increments of the tracers above those found in the background (or the lead vehicle). The chemical mass balance will be performed based on the chemical profiles obtained from the source samples for the tailpipe and the crankcase.
SUMMARY

PM$_1$, ultrafine particle counts, and black carbon were generally greater inside the bus than inside the lead vehicle, indicating self-pollution using the lead-vehicle approach. The average differences in the PM$_1$, ultrafine particle counts, and black carbon between the bus and the lead vehicle were smaller when windows were open on the bus. These findings suggest that ventilating the bus dilutes these species and reduces self-pollution levels. Previous research has shown a similar relationship between window configuration and on-bus concentrations of diesel exhaust.$^{5-10}$

The PM$_{2.5}$ and PAH measurements, on the other hand, were generally greater in the lead vehicle than on the bus. The lead vehicle measurements represent over-the-roadway conditions, which include a variety of sources, including resuspended dust. The resuspended dust is comprised mostly of coarse fine particles, some of which are captured by the PM$_{2.5}$ impactor. The sources of the PAHs are being investigated. Based on our findings, PM$_{2.5}$ and PAH do not appear to be good indicators for detecting diesel bus self-pollution using the lead-vehicle approach. Results from the lead vehicle approach will be compared with those from the tracer approach and the chemical mass balance model.

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REFERENCES


