Philip K. Hopke, Ph.D., is the Bayard D. Clarkson Distinguished Professor and Director of the Center for Air Resources Engineering and Science at Clarkson University

I find the experimental measurements disappointing. The instruments chosen are not the most accurate and precise that could have been used. They could have used batteries and an inverter to power a much better quality CPC and a nephelometer that had better response below 0.1 μm. If they had been on a bus with people riding on it or where making personal measurements, their choice of measurement systems would make sense, but given the nature of the study, the lack of best practice instruments is disappointing. They have missed an opportunity to make a real contribution to the problem. Since diesel has a peak around 70 nm, they are underestimating the PM2.5 mass with the DataRAM. Since 70 nm particles deposit much more effectively than 0.25 μm particles, lack of data in this size range is a significant deficiency. An instrument like an FMPS would have proven much more useful because they could get high time resolution measurements from 5.6 to 560 nm.

They also substantially underestimate the ultrafine particles (<20nm) with the PTrak. They state "This study illustrates that the P-Trak is a good instrument for measuring particulates that have aged." However, their set-up is such that the particles have not had time to age and thus, they are missing the large number of 10 to 20 nm particles. Even the 3022 that was used in comparison in the quoted study is an old design instrument. I would have looked at a 3781 with a 50% cut point of 6 nm to properly characterize the ultrafine particle number concentrations.

I have never used the DataRAM-4 monitors. These are the next generation monitors after the DataRAM 2000s. We have the personal DataRAM 1000 and 1200s, which are meant to be worn. The DataRAM-4 is a portable but not a personal monitor. Regardless, I expect that some of the same limitations will hold. The investigators did a decent job characterizing the instruments before the initial study at different concentrations using a like source of particles. However, you see that the coefficient of variation (Tables 3 and 4) is fairly high, especially for low concentrations. Also, there appears to be a predictable bias among the monitors (e.g., Fig 22 and calibration curves).

As far as I can tell from the report, the calibration curves that were developed were not used to correct the data from the monitors, even though the slopes and intercepts are not close to 1 and 0, respectively. Also, the monitors were recalibrated before the final study so the calibration curves would not be applicable. No collocation experiment was conducted following the recalibration, unless I missed something. Therefore, the reported results likely have a monitor bias. This could be why the ambient monitor is higher than the monitors in the bus. However, there is also the issue of pollutants building up in the vicinity of the track from the exhaust and resuspended dust (a bigger issue for the initial study where the ambient measurement was in the center of the track).

I did not see calibration curves for the gaseous species using the SEMTECH-D gas analyzer. We have no information on its accuracy and precision.

The work they did to seal the leaks may make the bus they used unrepresentative of the bus fleet. Are most buses really sealed properly? Thus, in actual practice, the exposure would be much higher.

I found the beginning of the report hard to read since they outlined the experimental design with the names of the instruments before defining the nature of the instruments. I knew what they were, but I suspect that many less versed in particle measurements will have a tough time with that section.

I am not sure why they made runs with the windows open. One would have expected dilution and infiltration of the ambient aerosol. Why seal the doors and then open the windows? Those runs could have been used more profitably.

They have evaluated the technology on a bus. However, I wonder how well the retrofits are installed on a fleet and how well they are maintained. Such information was beyond the scope of this study, but clearly there is a need to look at how these technologies work in real applications and over time.

A reference they should review is

Title: Predicting airborne particle levels aboard Washington State school buses
Author(s): Adar SD, Davey M, Sullivan JR, et al.
Source: ATMOSPHERIC ENVIRONMENT Volume: 42 Issue: 33 Pages: 7590-7599
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Dear Dr. Bonanno:

Following please find my review comments on the "In-Cabin Particulate Matter Quantification and Reduction Strategies Final Report" by Investigators at Rowan University, dated 12/8/2008. The review was conducted focusing on the six charge questions provided by New Jersey Department of Environmental Protection.

Charge Questions:

1. Based on your interpretation of the report, can you identify one or more technologies that would be effective in significantly reducing in-cabin $PM_{2.5}$, and /or Ultrafne Particulate Matter (UFPM)?

Based on data presented in the report, the efficiency of various retrofit technologies to reduce in-cabin $PM_{2.5}$ levels ranked as: DPF+CCVS>DPF>FTF+CCVS. All of these three technologies achieved over 250% $PM_{2.5}$ reduction from the baseline. Neither CCVS nor FTF produced significant reductions on $PM_{2.5}$.

For UFPs, a single CCVS or its combinations with DPF or TFT helped to reduce the in-cabin particle number concentrations. A single DPF or TFT did not contribute significantly to the reduction of UFPs.

For gaseous pollutants, two tailpipe retrofit technologies (DPF and TFT) showed significant reduction.

2. Are there major problems with the data analysis and/or interpretation that require correction before the results of the study are useable?

I have three major concerns about the study design, data analysis and interpretation, and the conclusions made in the study.

First, although the investigators took great care to make sure there was no other major PM source other than the bus own emissions when designed the study, sealing the rear door and windows may not reflect realistic driving conditions under which the bus is used to pick up and drop-off children. Using an over sealed bus also makes it difficult to draw any conclusions on retrofit technologies targeting on tailpipe emissions. In fact, the apparently high efficiency of CCVS and low efficiency of DPF for in-cabin pollutant concentration reduction may be due to the fact that DPF's effects, if any, were diminished by not allowing tailpipe emissions entering the school bus cabin.

Second, the crank system usually emits greater amount of larger particles than ultrafine particles, as the investigators mentioned in the report. Thus, a CCVS is expected to produce more benefits for larger particles, say $PM_{2.5}$, than ultrafines. However, the data reported in this study suggested that CCVS works better to reduce in-cabin ultrafine particles than $PM_{2.5.}$ This is confusing and needs better explanation.

Third, greater variability of $PM_{2.5}$ levels from Run 7F to 19F, and UFPs levels throughout the study were observed, which may weaken the conclusions made in the report. This is especially true for UFPs analysis. Since the engine oil temperature is a major factor affecting UFP emissions, extrapolating the data out of the measured temperature range to draw conclusions is risky. It is better to control the engine oil temperature and reduce its variation before compare the in-cabin pollutant concentrations.

3. On pages 93-95, the investigators perform an ANOVA on the $PM_{2.5}$ and UFPM in- cabin concentrations with and without retrofit devices.

3a. Is this an appropriate statistical test for this data?

ANOVA is a statistical method to analyze if the mean of variables are different. It is an appropriate statistical test for the type of data reported in the current study. However, to use ANOVA, several assumptions should be satisfied: (1) normality of the data (2) variances are equal, and (3) independence of the data points. If more than one of these assumptions is violated, transformation is needed or non-parametric test has to be used. So in this report the assumptions should be checked and stated before using ANOVA.

3b. If yes, are the investigators' conclusions based on the results of this test appropriate? See Conclusion #5, i.e., that the crankcase ventilation system (CCVS) alone does not reduce $PM_{2.5}$ based on the results of the ANOVA analysis

As mentioned in 3a, although ANOVA is appropriate for this type of data analysis, it is important to check for the three assumptions that ANOVA requires. It is not clear from the report whether these assumptions hold for the data used in achieving the conclusions regarding CCVS reducing $PM_{2.5}$ levels.

RE: High Ambient $PM_{2.5}$ Measurements: see Figure 47, page 77
4a. During runs 7F-19F, is it reasonable that the ambient measurements were higher than the in-bus measurements?

This may be due to the over sealed study design. When there is no significant PM sources penetrate into the school bus cabin, the PM concentrations inside the bus could decay due to particle deposition onto interior surfaces. Thus, for a well-sealed bus, it is possible for in-bus concentrations to be lower than the ambient concentrations.

4b. In your opinion, does this reflect actual conditions or to what extent do you think that this may reflect inaccuracies in data handling or in the measurement of either the ambient particulates or the in-bus particulates?

This may not reflect actual conditions when a regular (not sealed) bus was driven on roadways. It has little to do with inaccuracies in data handling or in the measurement of either the ambient or in-bus particulates. Instead, it came from a study design issue where a usually leaky bus was over sealed.

4c. Additionally, since runs 7F, 11F and 12F had extremely high ambient measurements resulting in large negative values for in-bus particulates when the ambient values are subtracted out, would this be justification to not use those runs in analysis/conclusions?

Data from these runs should be eliminated in any analysis regarding retrofit technology efficiency. As mentioned above, this phenomenon is likely due to particle deposition inside the bus under well-sealed conditions not a benefit from retrofit technologies.

4d. In your opinion, is it appropriate to conclude that a technology (or combination of technologies) was more effective because that condition produced a more negative value when the high ambient value was subtracted out?

It depends. If all the runs were conduced under the same ambient condition, following the same protocol, then such conclusion can be made. However, the data suggest a huge variability in both ambient and in-bus particulate concentration levels. Thus, making conclusions simply based on more negative values is risky.

5. Is it reasonable that while the DPF alone did not impact ultrafine particulate matter (UFPM) and possibly increased them, and the CCVS reduced UFPM somewhat, that the combination of DPF and CCVS almost completely eliminates UFPM?

It is reasonable that the efficiency of DPF+CCVS was much higher than any single one if the following assumptions are met:

(1) There were much more large size particles than small size particles emitted from the crankcase vent.
(2) The crankcase emission is the major source of in-cabin UFPs.
(3) CCVS only worked to remove large size particles and turn them into smaller size particle.
(4) DPF only worked to remove smaller size particles.

If all above assumptions were met, we could explain the result as follow:

(1) Since the in-cabin UFPs mainly came from the crankcase emission, the tailpipe retrofit technology did not work efficiently to reduce UFPs. However, due to the over sealed study design; it is difficulty to make any conclusions on the tailpipe retrofit technology based on data collected in this study.
(2) CCVS removes large size particles so that the result of single CCVS application showed some efficiency.
(3) Since large size particles were more than small size in crankcase emission and CCVS turned them into smaller size, most of the particulate matters became smaller size particles which could be removed by DPF.
(4) The small size particles in the tailpipes were removed efficiently by DPF.

If any of the assumptions could not be satisfied, it will be not reasonable to expect such high reduction of UFPs from CCVS+DPF, while either single technology did not work very well.

6. The study claims that the use of a CCVS alone reduces UFPM and not $PM_{2.5}$. Is that reasonable in your opinion?

As mentioned in question No. 2, one of my major concerns is the conclusion on CCVS on reducing UFPM but not $PM_{2.5}$. UFPM tested in this study is the number concentration of ultrafine particles whose diameters range from 0.02 µm ~ 1 µm. $PM_{2.5}$ is the mass concentration of fine particles with diameters less than 2.5 µm. For vehicular emitted particles, over 90% by number was in the UFP size range, but their mass concentrations were quite low because of the small size. UFPM number concentrations and PM2.5 mass concentrations usually don't correlate. This, it is possible for one technology to remove a large amount of UFPs but not reduce the mass concentration of $PM_{2.5}$. However, it is well-know, as the investigators also mentioned in the report, that the crank system usually emits greater amount of larger particles than UFPM. Thus, a CCVS is expected to produce more benefits for larger particles, say $PM_{2.5}$, than ultrafines. However, the data reported in this study suggested that CCVS works better to reduce in-cabin UFPM than $PM_{2.5.}$ In addition, the investigators stated that the sizes of the particles in the bus equipped with CCVS were smaller than the baseline (page 91), and concluded that CCVS had greatly reduced the fraction of larger particles from the crankcase vent, rather than small size particles. Overall, the investigators' conclusions on CCVS are confusing and needs better explanation.

Thank you for providing me with this opportunity to review the final report. Should you have any questions, please do not hesitate to contact me by phone: 310-923-6932 or email: yifang.zhu@tamuk.edu.

Sincerely yours,

Yifang Zhu
Assistant Professor