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NANOPARTICLES FROM A CALIFORNIA IN-USE HEAVY TRUCK EQUIPPED WITH PM-NO$_x$ RETROFITS

Jorn D. Herner[1], William Robertson[1], Alberto Ayala[1], and Constantinos Sioutas[2]
[1]California Air Resources Board, [2] University of Southern California

Abstract

The California PM emission standard for new heavy-duty engines was reduced from 0.1 g/bhp-hr to 0.01 g/bhp-hr in 2007. Similarly, the corresponding NOx emission standard will be reduced from last year's 2 g/bhp-hr to an eventual 0.2 bhp-hr limit in a stepwise fashion between 2007 and 2010. While diesel engine manufacturers have been able to meet previous emissions standards with engine design and combustion process improvements, the new very low emission limits will require nearly universal use of advanced aftertreatment. Some of those devices such as DPFs and SCR are currently being investigated in retrofit demonstrations. Many studies have shown these devices to be very effective at reducing the mass emissions of the targeted pollutants. There is, however, remaining interest regarding how these aftertreatment devices may affect the emissions of ultrafine particles (solid and semi-volatile) and, in particular, the formation of nanoparticles. Some research has suggested that emissions of the very small particles may, under certain conditions, increase even as PM mass is decreased with the use of these aftertreatment devices. The volatility of the particles is a determining parameter.

In this work, we present our preliminary findings with respect to the particle number and particle size distribution measured in the emissions from one test vehicle, a heavy-duty diesel truck equipped with a demonstration retrofit for PM and NOx control. The study is being conducted at the California Air Resources Board's Heavy Duty Vehicle Emissions Laboratory (HDVEL) in Los Angeles. In our laboratory, vehicles are exercised on a chassis dynamometer and emission samples are collected in accordance with the established protocols promulgated in the United States Code of Federal Regulations for emission certification.

Project Overview

This project seeks to investigate the physicochemical and toxicological characteristics of exhaust emissions of in-use heavy- and light-duty motor vehicles projected to have significant share of the population and VMT in California. This study is a 4-year collaborative project focused on emerging issues of relevance for air quality and the protection of health. These issues include ultralow emissions from advanced aftertreatment technology, measurement instrumentation and protocols, and the relative toxicity of PM components. The project builds on previous vehicle emissions research by CARB [1, 2]. The premise for the study is the retrofit systems of today being a glimpse into the production-ready OEM systems of the future. And with an eye toward 2010 emission standards, the project seeks to address the following:

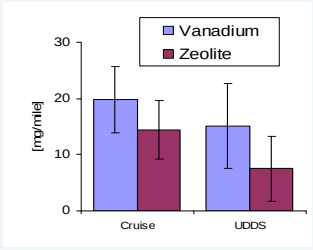
Hypothesis: (a) *Emerging, newer vehicle/engine systems will result in reduced emissions of physicochemical and toxicological relevance relative to existing, older systems*

Test fleets

Various types of retrofit systems for heavy-duty diesel (ULSD) applications are being investigated. These include two types of DPFs (a passive, catalyst-based DPF and an active, plug-in, uncatalyzed system), two SCR catalysts (vanadium-based and zeolite-based). A diesel hybrid electric (ERG + DPF) was also tested. The results are compared to a baseline vehicle (uncontrolled diesel). Testing of heavy-duty vehicles has just been completed in August 2007.

For the light-duty fleet, various fuel types are anticipated. A clean diesel vehicle certified to California standards, a gasoline vehicle (ultraclean and a high emitter), a CNG vehicle, an E85 vehicle, and a vehicle running on biodiesel are expected. This part of the project is planned for the 2008-2009 timeframe.

Figure 1. (a) Vehicle testing conducted at the CARB HDVEL. This test vehicle is a 1998 Class 8 Truck (>300K miles) powered by a Cummins M11 and equiped with a PM-NOx retrofit. *(b) PM-NOx Retrofit.* Tested in two versions for NOx control: (1) Vanadium-based catalyst and (2) Zeolite-based catalyst.



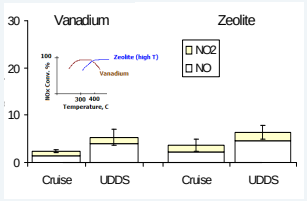


Figure 2. Preliminary PM Mass and NOx Emissions. The Vanadium-based system more effectively converts SO_2 to SO_3, and therefore emits more sulfate and PM overall. The activation temperature window for the two NOx catalysts is shown in the insert.

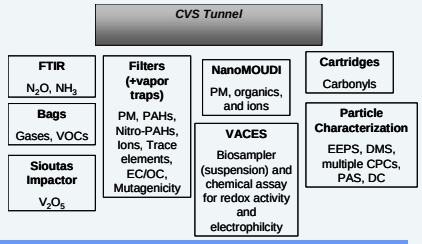


Figure 3. Emission Characterization Scheme. Sample collection of dilute exhaust from the CVS tunnel for physical, chemical, and toxicological characterization.

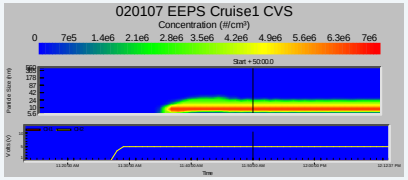


Figure 4. Results Particle Size Distribution – Cruise. Vanadium-based SCR catalyst. Here we see the delay between reaching top speed (50mph) and the onset of the nucleation mode, which does not set in until the exhaust temperature out of the SCR catalyst has reached approximately 310°C.

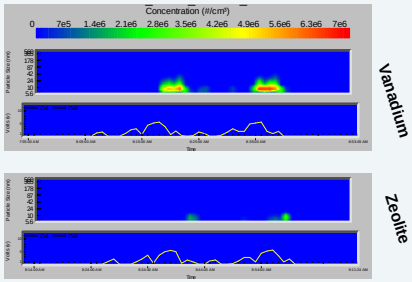


Figure 5. Results Particle Size Distribution - UDDS. Here are the EEPS results for the vanadium and zeolite systems over the UDDS cycle. The speed trace can be seen below. The two figures (*Fig 4 and 5*) are shown on the same scale to highlight the much larger nucleation mode with the vanadium system.

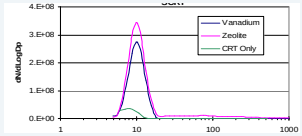


Figure 6. Average Particle Size Distribution. 50 mph Cruise. Size distributions are similar for both SCR systems. Notice the much diminished nucleation mode for a CRT system.

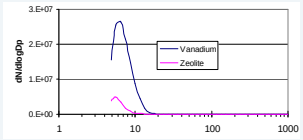


Figure 7. Average Particle Size Distribution. UDDS cycle. The nanoparticle emissions from the vanadium-based system are higher than the zeolite-based system due to the lower nucleation activation temperatures required.

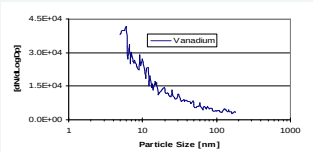


Figure 8. Average Particle Size Distribution. Idling operation. Particle concentrations are comparable to tunnel blanks. Similar for both vanadium and zeolite systems.

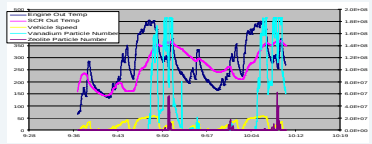


Figure 9. Particle Emissions. Vehicle operation over UDDS cycle. Nucleation occurs at SCR catalyst out temperature of ~310ºC for the Vanadium system, but at ~340ºC for the Zeolite system.

Summary

The preliminary findings presented here suggest that the tested PM-NOx retrofits (Vanadium SCR catalyst + DPF and Zeolite SCR catalyst + DPF) work very well and as designed yielding significant reductions of PM mass and NOx emissions over steady-state and transient (UDDS cycle) vehicle operation. California ULSD fuel (15 ppm S) was used for all tests. The presence of large nanoparticle emissions during cruise operation is evident. Although left for a future publication, sulfate was determined to be the principal component of PM emitted during cruise operation. Once the exhaust reaches the SCR catalyst activation temperature, nucleation of sulfate components results in the observed high nanoparticle concentrations. Transient operation resulted in lower nanoparticle emissions. Idling yielded concentrations similar to tunnel blanks. Measurements post-DPF, but prior to the SCR catalyst confirm that, in spite of the use of ULSD fuel, the effective nucleation of sulfate material in the exhaust is promoted by the SCR catalyst once its activation temperature is reached.

Next Steps

The testing of the heavy-duty vehicles is complete. We will procede to data analysis and interpretation and expect to begin reporting findings in the peer-review literature. In early 2008, the light-duty testing phase of the project will commence.

Research Team

Air Resources Board
USC
UCLA
UC DAVIS
UW-Madison

Co-sponsor:

California Energy Commission
SOUTH COAST AQMD

Principal in-kind contributors:

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References

1. Ayala, A., N.Y. Kado, R.A. Okamoto, B.A. Holmén, P.A. Kuzmicky, R. Kobayashi, and K.E. Stiglitz (2002) "Diesel and CNG Heavy-duty Transit Bus Emissions over Multiple Driving Schedules: Regulated Pollutants and Project Overview," *SAE Transactions Jornal of Fuels and Lubricants, 735-747*
2. Herner, J., A. Ayala, W.R. Robertson (2006) "Nanoparticle Formation in the Emissions from a Trap-Equipped Heavy Duty Diesel Truck" AAAR Conference Platform 12E4