Abstracts

Session 5 – Diesel and CNG Bus Emissions

STATE OF THE ART IN DIESEL EMISSION CONTROL

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ABSTRACT

The entire field of diesel emission control is developing rapidly. In addition to advances in exhaust emission control technology, regulatory proposals are approaching the U.S. 2010 levels in Japan and Europe, and the engines are getting cleaner.

This presentation will bring the audience up to date with the latest published information on the regulations, estimates of engine-out emissions, filter technology, NO_x technology, and integrating it all into viable systems for use in light- and heavy-duty applications.

In summary, it appears that nominally 80-percent filtration efficiency is needed to hit the Japanese 2005 and U.S. 2007 interim heavy-duty diesel regulations, while employing high levels of exhaust gas recirculation (EGR). In Europe, for both Euro 4 in 2005 and Euro 5 in 2008, 70-80 percent selective catalytic reduction (SCR) will be used in fuel-sensitive applications, while diesel oxidation catalysts (DOC's) and some filters will show up in others. In light-duty, depending on vehicle size and which engine technologies emerge, nominally 50 percent NO_x efficiency will be needed to hit proposed Euro 5 regulation in 2010 and 70-80 percent NO_x efficiency will be needed to hit the Bin 5 U.S. fleet average.

In the filter arena, improvements continue on regeneration strategies and filter performance. For NO_x control, SCR is progressing to commercialization, and the NO_x traps are in a rapid stage of development and improvement, with better materials and strategies for regeneration and desulfation. Integration of NO_x and PM control is entering the heavy-duty vehicle stage with SCR and filter systems on prototype vehicles, and NO_x trap and filter systems showing up on light-duty vehicles and on heavy-duty engine dynamometers.

SUMMARY OF SWEDISH EXPERIENCES ON CNG AND"CLEAN" DIESEL BUSES

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ABSTRACT

In Sweden, emission tests were conducted on compressed natural gas (CNG) and diesel buses in the 1990's as part of several governmental programs in this area. A summary of the evaluation presented at DEER 2001 is provided. In addition, a comparison between the Swedish results and some of the more recent results from the U.S. studies is made.

The analysis of the Swedish results showed considerable improvement on the diesel buses by reformulating the diesel fuel and by fitting aftertreatment devices. Particulate filters (DPF's) can reduce particle emissions from diesel buses to a level similar to that of the CNG buses. The NO_X emissions can be reduced by some 50 percent by using retrofit exhaust gas recirculation (EGR) systems, but the level was still higher than for the best CNG buses.

CNG had a positive impact regarding several of the effects investigated, e.g., acidification and local NO_2 emissions. In other cases (e.g., ozone-forming potential), the difference between the best options was small. The cancer risk index is largely dependent on the unit risk factors, but the overall result in this case did not vary much between the sets of risk factors used. Clean diesel fuel with a particulate trap and CNG/biogas were the options with the lowest cancer risk index. The impact on the greenhouse gas emissions was the most significant advantage for the biofuels.

It is interesting to note that there are both similarities and differences between the engine technology used in Sweden and the United States. First, it should be noted that the U.S. buses are relatively new, i.e., Model Year 2002-2001, while the Swedish tests originate from the 1990's. A large proportion of the diesel buses in Sweden use oxidation catalysts, DPFs or EGR in combination with DPF. Practically all CNG buses in Sweden are equipped with oxidation catalysts, whereas until recently, relatively few have been using oxidation catalysts in the United States. However, it is suspected that the first generation of CNG catalysts has poor durability. Closed loop control was not used on the older Swedish CNG buses but was introduced in 2002.

The "best" test results on CNG in Sweden indicated surprisingly low NO_X emissions in comparison to most U.S. results. A more advanced combustion system on the (newer) U.S. diesel engines yielded lower HC emissions and, thus, also less harmful toxic VOCs, e.g., PAH emissions and formaldehyde. The results for twelve tri+ PAH species analyzed in all studies were compared, indicating a great reduction potential for fuel reformulation and catalytic DPFs. The PAH level for CNG without catalyst was significantly higher, but the impact of a catalyst still has to be assessed. An efficient oxidation catalyst is also essential to achieve low levels of formaldehyde for CNG buses. The results on 1,3-butadiene tended to be somewhat inconclusive.

A valid conclusion from all test results is that aftertreatment devices are crucial to achieve low emissions, regardless of fuel used. It is expected that future development on engines and aftertreatment devices will diminish the advantage of the alternative fuels regarding many of the effects on health and environment. On the contrary, the impact on greenhouse gases from some biofuel options will be more pronounced in the future.

COMPARISON OF EXHAUST EMISSIONS, INCLUDING TOXIC AIR CONTAMINANTS, FROM SCHOOL BUSES IN COMPRESSED NATURAL GAS, LOW-EMITTING DIESEL, AND CONVENTIONAL DIESEL ENGINE CONFIGURATIONS

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ABSTRACT

In the United States, most school buses are powered by diesel engines. Some have advocated replacing diesel school buses with natural gas school buses, but little research has been conducted to understand the emissions from school bus engines. This work provides a detailed characterization of exhaust emissions from school buses using a diesel engine meeting 1998 emission standards, a low-emitting diesel engine with an advanced engine calibration and a catalyzed particulate filter, and a natural gas engine without catalyst. All three bus configurations were tested over the same cycle, test weight, and road load settings. In addition, the quantitative results from this study were used to calculate cancer potency weighted emissions.

Twenty-one of the 41 "toxic air contaminants" (TAC's) listed by the California Air Resources Board as being present in diesel exhaust were not found in the exhaust of any of the three bus configurations, even though special sampling provisions were utilized to detect low levels of TAC's. Although there were no significant differences between the low-emitting diesel and the natural gas bus configurations for 14 TAC's, the low-emitting diesel bus configuration had significantly lower emission levels than the natural gas bus configuration for aldehydes, ketones, and benzene. Overall, the results demonstrate that low-emitting diesel technology had the lowest level of both EPA-regulated emissions and TAC's.

COMPARISON OF CLEAN DIESEL BUSES TO COMPRESSED NATURAL GAS BUSES

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ABSTRACT

Using previously published data on regulated and unregulated emissions, this paper will compare the environmental performance of current- generation transit buses operated on compressed natural gas (CNG) to current-generation transit buses operated on ultra-low sulfur diesel fuel (ULSD) and incorporating diesel particulate filters (DPF). Unregulated emissions evaluated include toxic compounds associated with adverse health effects (PAH, NPAH, benzene) as well as particulate matter (PM) particle count and size distribution.

For all regulated and unregulated emissions except NO_x, both technologies are shown to be comparable, with virtually identical levels of PM emissions, toxic emissions, and particle number emissions. DPF-equipped buses are shown to have lower HC and CO emissions than CNG buses. CNG buses are shown to have NO_x emissions that average 25 percent less than NO_x emissions from DPF-equipped buses, though CNG bus NO_x emissions are shown to be much more variable.

In addition, this paper will compare the capital and operating costs of CNG and DPF-equipped buses. The cost comparison is primarily based on the experience of MTA New York City Transit in operating CNG buses since 1995 and DPF-equipped buses fueled with ULSD since 2001. Published data on the experience of other large transit agencies in operating CNG buses is used to validate the NYCT experience.

The incremental cost (compared to "baseline" diesel) of operating a typical 200-bus depot is shown to be six times higher for CNG buses than for "clean diesel" buses. The contributors to this increased cost for CNG buses are almost equally split between increased capital costs for purchase of buses and installation of fueling infrastructure, and increased operating costs for purchase of fuel, bus maintenance, and fuel station maintenance.

COMPRESSED NATURAL GAS AND DIESEL TRANSIT BUS EMISSIONS IN REVIEW

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ABSTRACT

Over the past 3 years, the California Air Resources Board (CARB), in collaboration with the University of California and other entities, has investigated the tailpipe emissions from three different late-model, in-use heavy-duty transit buses in five different configurations. The study has focused on the measurement of regulated emissions (NO_x, HC, CO, total particulate matter [PM]), other gaseous emissions (CO_2, NO_2, CH_4, NMHC), a number of pollutants of toxic risk significance (aromatics, carbonyls, PAH's, elements), composition (elemental and organic carbon), and the physical characterization (size-segregated number count and mass) of the particles in the exhaust aerosol. The impact of oxidation catalyst control for both diesel and compressed natural gas (CNG) buses and a passive diesel particulate filter (DPF) were evaluated over multiple driving cycles (idle, 55-mph cruise, CBD, UDDS, NYBC) using a chassis dynamometer. The database of results is large, and some findings have been reported already at various forums including last year's DEER Conference. The goal of this paper is to offer an overview of the lessons learned and attempt to draw overall conclusions and interpretations based on key findings to date. To the extent possible, our results are compared to those from other similar studies.

HEAVY-DUTY VEHICLE IN-USE EMISSION PERFORMANCE

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ABSTRACT

Engines for heavy-duty vehicles are emission certified by running engines according to specified load pattern or duty cycle. In the United States, the U.S. Heavy-Duty Transient cycle has been in use already for a number of years, and Europe is, according to the requirements of the Directive 1999/96/EC, gradually switching to transient-type testing.

Evaluating the in-use emission performance of heavy-duty vehicles presents a problem. Taking engines out of vehicles for engine dynamometer testing is difficult and costly. In addition, engine dynamometer testing does not take into account the properties of the vehicle itself (i.e., mass, transmission, etc.). It is also debatable how well the standardized duty cycles reflect real-life driving patterns.

VTT Processes has recently commissioned a new emissions laboratory for heavy-duty vehicles. The facility comprises both engine test stand and a fully transient heavy-duty chassis dynamometer. The roller diameter of the dynamometer is 2.5 m. Regulated emissions are measured using a full-flow CVS system. The heavy-duty vehicle chassis dynamometer measurements (emissions, fuel consumption) have been granted accreditation by the Centre of Metrology and Accreditation (MIKES, Finland).

A national program to generate emissions data on buses has been set up for the years 2002-2004. The target is to generate emission factors for some 50 different buses representing different degree of sophistication (Euro 1 to Euro5/EEV, with and without exhaust gas aftertreatment), different fuel technologies (diesel, natural gas) and different ages (the effect of aging). The work is funded by the Metropolitan Council of Helsinki, Helsinki City Transport, The Ministry of Transport and Communications Finland, and the national gas company Gasum Oy.

The International Association for Natural Gas Vehicles (IANGV) has opted to buy into the project. For IANGV, VTT will deliver comprehensive emissions data (including particle-size distribution and chemical and biological characterization of particles) for up-to-date diesel and natural gas vehicles.

The paper describes the methodology used for the measurements on buses, the test matrix, and some preliminary emissions data on both regulated and unregulated emissions.

COMPARATIVE STUDY ON EXHAUST EMISSIONS FROM DIESEL AND COMPRESSED NATURAL GAS POWERED URBAN BUSES

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ABSTRACT

A couple of years ago, ADEME engaged in programs dedicated to emissions studies of the exhaust from urban buses. The measures associated with the reduction of atmospheric and noise pollution have particular importance in the sector of urban buses. In many cases, they illustrate the city's environmental image and contribute to reinforcing the attractiveness of public transport. France's fleet in service, presently put at about 14,000 units, consumes about 2 percent of the total energy of city transport. It causes about 2 percent of the HC emissions and from 4 to 6 percent of the NO_x emissions and particles. These vehicles typically have a long life span (about 15 years) and are relatively expensive to buy, about €150,000 per unit.

Several technical solutions were evaluated to quantify, on a real-condition cycle for buses, pollutant emissions and fuel consumption on one hand and reliability and cost in real existing fleets on the other hand.

This paper presents the main preliminary results on exhaust emissions from urban buses for two different cases:

- existing diesel buses, with fuel modifications (diesel with low-sulfur content, diesel with water emulsion, and biodiesel [30 percent oil ester in standard diesel fuel]) and
- renovated CNG-powered Euro II bus fleet

over representative driving cycles, set up by ADEME and partners. On these cycles, pollutants (regulated and unregulated) were measured as well as fuel consumption at the beginning of a program and 1 year after to quantify reliability and increase/decrease of pollutant emissions.

At the same time, some aftertreatment technologies were tested under real conditions and in several vehicles. Information such as fuel consumption, lubricant analysis, and problems of the technology were followed during a 1-year program.

On the overall level, it is the combination of various action, pollution reduction, and renewal that will make it possible to meet the technological challenge of reducing emissions and fuel consumption by urban bus networks.

STATE-OF-THE-ART AND FUTURE DEVELOPMENTS IN NATURAL GAS ENGINE TECHNOLOGIES

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ABSTRACT

Current, state-of-the-art natural gas engines provide the lowest emissions commercial technology for use in medium- to heavy-duty vehicles. NO_x emission levels are 25-50 percent lower than October 2002 diesel engines, and particulate matter (PM) levels are 90 percent lower than non-filter equipped engines. Yet, in common with diesel engines, natural gas engines are challenged to become even cleaner and more efficient to meet environmental and end-user demands. Cummins Westport is developing two streams of technologies to achieve these goals for medium-heavy and heavy-heavy duty applications.

For medium-heavy duty applications, lowest possible emissions are sought on SI engines without significant increase in complexity and with improvements in efficiency and BMEP. The selected path builds on the capabilities of the Cummins Westport, Inc., Plus technology and recent diesel engine advances in NO_x controls, providing the potential to reduce emissions to 2010 values in an accelerated manner and without the use of selective catalytic reduction (SCR) or LNA technology.

For heavy-heavy duty applications where high torque and fuel economy are of prime concern, the Westport-Cycle™ technology is in field trial. This technology incorporates high-pressure direct injection (HPDI) of natural gas with a diesel pilot ignition source. Both fuels are delivered through a single, dual common rail injector. The operating cycle is entirely unthrottled and maintains the high compression ratio of a diesel engine. As a result of burning 95 percent natural gas rather than diesel fuel, NO_x emissions are halved, and PM is reduced by around 70 percent. High levels of exhaust gas recirculation (EGR) can be applied while maintaining high combustion efficiency, resulting in extremely low NO_x potential.

Some recent studies have indicated that diesels equipped with diesel particulate filters (DPF) emit fewer nanoparticles than some natural vehicles. It must be understood that the ultra fine particles emitted from SI natural gas engines are generally accepted to consist predominantly of VOC's and that lubricating oil is a major contributor. Fitting an oxidation catalyst to the natural gas engine leads to a reduction in nanoparticle emissions in comparison to engines without aftertreatment.

In 2001, the Cummins Westport Plus technology was introduced with the C Gas Plus engine, a popular choice for transit bus applications. This incorporates drive by wire; fully integrated, closed loop electronic controls; and a standard oxidation catalyst for all applications. The B Gas Plus and the B Propane Plus engines, with application in shuttle and school buses, were launched in 2002 and 2003. The gas-specific oxidation catalyst operates in concert with an optimized ring-pack and liner combination to reduce total particulate mass below 0.01g/bhp-hr, combat ultra fine particles, and control VOC emissions.