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Overview - Retrofitment of Heavy Duty Diesel Vehicles

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Session 6

Retro-fitment of Buses & Trucks

Society and Mobility

Impacts of rapid motorization

- Increase in vehicle ownership
- Decrease in public transport shares
- Congestion (reduction in travel speed)
- Increase in accidents and fatalities
- Increase in air pollution.

Air Quality ?

- Diesel engines are important power systems for on-road and off-road vehicles.
- These reliable, fuel-efficient, high-torque engines power many of the world's heavy-duty trucks, buses, and off-road vehicles.
- Diesel engines are easy to repair, inexpensive to operate, and extremely durable.
- It is common for a diesel engine to last 15-20 years and achieve a one million-mile life.
- From the standpoint of greenhouse gas emissions, diesel engines can compete with other advanced technologies, like hybrid electric vehicles, due to a diesel engine's inherent fuel economy relative to conventional spark-ignited, gasoline engines. Diesel-powered vehicles have demonstrated a 30-40% fuel economy advantage over their gasoline counterparts. This translates to about a 20% reduction in CO2 emissions.

- **Diesel engines provide excellent fuel economy, high torque at low speeds and durability advantages for large heavy-duty trucks, buses, and off-road equipment.**
- **Vehicle emissions are one of the major contributing factor to poor air quality.**
- **Key emissions from vehicles include carbon monoxide (CO), unburned hydrocarbons (HC) and volatile organic compounds (VOC), nitrogen oxides (NOx), and particulate matter (PM).**
- **Diesel exhaust is classified as a known or probable human carcinogen. Particles emitted from diesel engines are small – in most cases less than 2.5 microns in diameter. Because of their extremely small size and composition, the particles emitted by diesel engines have raised many health concerns. Children are especially vulnerable to air pollution because they have growing and developing bodies and breathe in more air per unit of body weight than adults.**
- **PM, black carbon, NOx are major emissions from diesel. Normally, CO and HC are well controlled emissions from a diesel engine combustion.**

According to the World Business Council for Sustainable Development, global personal and goods transport is expected to grow rapidly through 2050, which will drive the worldwide demand for fuel, expected to double by 2050 from present levels of demand.

This scenario presents demanding challenges for all involved in the transportation sector to reduce both harmful exhaust emissions and fuel consumption.

- Older diesel vehicles, including buses, are said to be a major source of carbon dioxide (CO2) emissions and black carbon that contribute to the transportation sector's impacts on climate change and a country's dependence on oil.
- With the aging of engine, CO and HC emissions may exceed and become an issue in addition to NOX, PM and black carbon issues. Old / tampered / unmaintained diesels emit higher emissions.
- Depending on the type and age of the vehicle, bus emissions may make their way into the bus cabin. The pollution comes from two sources (a) the tailpipe and the (b) engine crankcase. Even though children may spend only a small portion of their day on buses, the high exposures they receive inside the bus can add considerably to their daily and annual exposures.
- In industrialized countries, even as cleaner vehicles are replacing older and dirtier ones and total transportation emissions are beginning to decline due to stringent emission regulations, vehicles are still a significant source of air pollution.
- In developing and transition countries, vehicle numbers are growing exponentially and, without strict controls in place, emissions from transportation sources are becoming an increasingly urgent concern.

Diesel emissions and health :

- **Diesel exhaust contributes to respiratory and cardiovascular diseases, including lung cancer.**
- **Toxic emissions from diesel school bus tailpipes and crankcases pollute bus interiors, as well as outdoor air.**
- **Bus riders and drivers may be exposed to these pollutants for extended periods.**
- **Children, with their developing lungs and higher respiratory rates, are especially vulnerable.**

The carbonaceous component of PM (black carbon) has been found to be a significant contributor to the atmospheric warming effect by enhancing the absorption of sunlight. The global warming potential of black carbon has been estimated to be significantly several times higher than that of CO2 on unit emission basis.

Black carbon particles remain airborne for few weeks, therefore, removing black carbon from diesel exhaust has an immediate benefit to both global warming and public health.

The NOx emissions also pose a number of health concerns. Once in the atmosphere, NOx react with volatile organic compounds (VOCs) in the presence of sunlight to form **Ozone**. Ozone is a reactive and corrosive gas that contributes to many respiratory problems. Ozone is particularly harmful to children and the elders.

NOx emissions are also a major contributor to the PM2.5 inventory when they react in the atmosphere with ammonia and other gases to form nitrate particles as secondary PM2.5.

- Despite health and environmental concerns, the diesel engine remains a popular means of powering trucks, buses and other heavy equipment.
- Diesel engines are reliable, durable, fuel efficient, easy to repair and relatively efficient to operate. In heavy-duty trucks, some engines have achieved operating lives of 1,000,000 miles; some engines power city buses for up to 15 to 20 years.
- Because of the above attributes and better fuel economy and lower CO2 emissions, diesel engines is a popular and significant powertrain for several applications.

- **A number of countries worldwide, including India, have established significantly lower exhaust emission limits for new diesel engines. India will be leap-frogging to BS6 in 2020 from BS4 in 2017.**
- **However, due to the very long operating lives of many diesel engines, older uncontrolled diesel vehicles will continue to be used in particularly heavy-duty vehicle fleet – public and goods transportation.**
- **Inspite of stricter regulations, on any day on the coming years, more than 75% older vehicles (BS2 and BS3) will co-exist on the road emitting higher emissions due to aging. This scenario completely dilutes the benefits of newly introduced low emitting vehicles.**
- **To achieve air quality control aligned with tighter regulations, there is increasing interest to retrofit older, "dirtier" diesel engines while newer, "cleaner" diesel engines enter the marketplace.**

IN-USE DIESEL EMISSION REDUCTION PROGRAMS

Diesel retrofit programs are successfully employed worldwide by regions like U.S. EPA, California ARB, the state of New Jersey, New York, Texas, Illinois, New York City, Hong Kong, Japan, South Korea, Mexico, and Sweden. China, Thailand, India and Chile are also considering the retrofit programs seriously.

OPTIONS to control emissions from old engines / vehicles :

- **Refuel the engine:** Cleaner fuels and ultra-low sulfur diesel fuel will have a direct impact on emission levels. It will also enable the use of advance emission control technologies that will further reduce vehicle emissions.
- **Retrofit the engine:** Installing emission control technologies on older vehicles. This can be a very effective option for reducing harmful emission levels particularly from bus fleets. Lifetime of urban buses is usually long and hence with aging, emit higher emissions (PM, black carbon, CO, HC). The buses drive frequently in densely populated areas. Therefore, bus retrofit program is cost effective strategy for reducing emissions in urban areas.
- **Repower the engine:** A bus chassis has a long useful life in decades. The emissions performance of older buses can be improved by removing the entire existing engine and repowering the bus with a new or newer vintage engine emitting lower than the existing engine that is proposed to be replaced.
- **Rebuild the engine :** A diesel engine is rebuilt with new components, rather than replaced, when it reaches the end of its useful lifetime. Current regulations allow the engine to be rebuilt to meet the standards in effect at the time of manufacture.
- **Replace the vehicle:** Retire older buses and replace by substantially cleaner and more fuel efficient buses. New buses could be advanced diesel buses using ultra-low sulfur fuel and advanced emission control technologies, hybrid and compressed natural gas (CNG) buses. These buses will be fuel-efficient also.

Diesel Retrofit Programs

Successful implementation and operation of a diesel retrofit program could depends on a number of elements :

- suitability of vehicles for retrofitment
- the emission reductions that are desired or required
- Duty cycle, operation pattern, exhaust temperature profile pattern
- the appropriate emission control technology for each vehicle
- fuel quality needs (e.g., sulfur level; ideally, ULSD should be used)
- operational and maintenance requirements
- training and education needs of vehicle operators and the public
- Administrative supports

For optimum results, the engine of a vehicle should be rebuilt to the manufacturer's specifications before a catalyst, filter system or other emission control device is installed.

RETROFITMENT DEVICES

- **Diesel oxidation catalysts (DOCs)** installed on a vehicle's exhaust system can reduce total PM by as much as 25 to over 50 percent, depending on the composition of the PM being emitted. Diesel oxidation catalysts can also reduce smoke emissions from older vehicles and virtually eliminate the obnoxious odors associated with diesel exhaust. Oxidation catalysts can reduce more than 90 percent of the CO and HC emissions and more than 70% of the toxic hydrocarbon emissions in diesel exhaust.
- **Wall-flow diesel particulate filters (DPFs)** have been widely retrofitted on on- and off-road in-use diesel vehicles. DPFs can achieve up to and, in some cases, greater than a 90 percent reduction in PM. Filters are extremely effective in controlling the carbon fraction of the particulate known as black carbon. **Regeneration is necessary**. Black carbon has been recently identified as a significant contributor to global warming with a CO2 equivalence estimated to be hundreds times that of carbon dioxide. DPFs are also the most effective devices to control emissions of ultrafine particles emitted from diesel engines.
- **Particulate filters can be combined with a DOC or directly catalyzed** to control up to 90 percent or more of the toxic HCs emitted by a diesel engine. **On-line passive regeneration is associated.** The DPFs incorporating a catalyst function have been shown to decrease the levels of polyaromatic hydrocarbons, nitro-polyaromatic hydrocarbons, and the mutagenic activity of diesel PM.
- **Flow-through or partial filters (DoC+)** are a relatively new method for reducing diesel PM emissions. Flow-through filters employ catalyzed metal wire mesh structures or tortuous flow, metal foil-based substrates with sintered metal sheets to reduce diesel PM. Flow-through filters are capable of achieving PM reduction of about 30 to 50 percent, depending on the engine operating characteristics. Because of their open structure, these devices are less prone to plugging and may be more suited to older diesel engines with higher engine-out PM levels.

RETROFITMENT DEVICES

- **Exhaust gas recirculation (EGR)** systems have been retrofitted on heavy-duty diesel vehicles. EGR is capable of achieving a 40 percent reduction in NOx emissions or more. However, capability of adapting / withstanding the reduction in air mass should be examined, else there will be increased power loss and smoke and PM emissions.
- **Selective catalytic reduction (SCR)** using urea as a reducing agent has been shown to be effective in reducing NOx emissions by up to 90 percent while simultaneously reducing HC emissions by 50 to 90 percent and PM emissions by 20 to 30 percent.
- **Lean NOx Catalysts or HC-SCR** have been installed on heavy-duty on-road and off-road vehicles in combination with a DPF and are capable of achieving from 25-40 percent NOx reduction. These devices rely on the use of on-board diesel fuel from the vehicle as the reducing agent.
- **Lean NOx Trap Storage Catalysts (LNT)** – Have been successfully used on new light and medium-duty vehicles with over 80 percent NOx conversion. One experimental retrofit LNT system using syngas to regenerate the trap is being demonstrated on medium duty trucks.
- **Closed crankcase ventilation** technology can be retrofitted on turbocharged diesel engines to eliminate crankcase emissions. Crankcase gases impacts students on the bus. Emissions from the engine compartment seep through cracks and openings in windows and doors to create conditions in which the particulate matter concentrations inside the bus may be many times that of ambient conditions.

Exhaust Gas Recirculation (EGR)

Retrofitting exhaust gas recirculation on a diesel engine offers an effective means of reducing NOx emissions from the engine. Both low-pressure and high-pressure EGR systems exist but **low-pressure EGR is used for retrofit applications because it does not require engine modifications. However, EGR is limited by reduction in engine breathing capacity.**

Matching a Retrofit Technology to an Engine and Vehicle Application

When deciding whether to retrofit an in-use diesel-powered vehicle with a control technology, several factors must be considered, including:

- engine size and backpressure specification,
- engine duty-cycle and resultant exhaust gas temperatures,
- fuel sulfur level (< 15/50 ppm sulfur fuel)
- desired emission reductions, and
- vehicle integration and safety.

All of these items should be discussed with the technology provider.

Specially, school buses must be retrofitted with closed crankcase ventilation systems (CCVS). School buses used to transport children are required to install closed crankcase ventilation system (CCVS) devices on the engine crankcase. The CCVS is designed to capture and filter diesel engine crankcase vent emissions and redirect those emissions into the combustion process.

The type of retrofit device(s) for a particular bus will be determined based on three key criteria:

- **the potential to reduce exposure of the bus occupants to particulate matter (PM);**
- **attaining the largest emissions reductions possible for the service lifetime of the bus;**
- **the compatibility between the retrofit device and the bus engine.**

Impact of Sulfur in Diesel Fuel on Catalyst Technologies

- The sulfur content of diesel fuel is critical to applying catalyst technology.
- Catalysts used to oxidize the SOF of the particulate can also oxidize sulfur dioxide to form sulfates, which is considered part of the particulate.
- This reaction is not only dependent on the level of sulfur in the fuel, but also the temperature of the exhaust gases.
- Catalyst formulations have been developed which selectively oxidize the SOF while minimizing oxidation of the sulfur dioxide. However, the lower the sulfur content in the fuel, the greater the opportunity to maximize the effectiveness of oxidation catalyst technology for both better total control of PM and greater control of toxic HCs.

The availability of low sulfur fuels will allow off-road engines to fully take advantage of catalyst technology for both original equipment and retrofit applications similar to the experience already available for on-road vehicles.

Impact of Sulfur in Diesel Fuel on Diesel Particulate Filters

- Sulfur in diesel fuel significantly affects the reliability, durability, and emissions performance of catalyst-based DPFs.
- Sulfur affects filter performance by inhibiting the performance of catalytic materials upstream of or on the filter.
- Sulfur also competes with chemical reactions intended to reduce pollutant emissions and creates particulate matter through catalytic sulfate formation.
- Catalyst-based diesel particulate filter technology works best when fuel sulfur levels are less than 15 ppm.
- In general, the less sulfur in the fuel, the better the technology performs. **The use of ultra-low sulfur diesel fuel (15 ppm sulfur maximum) greatly facilitates filter regeneration at lower temperatures in passive DPF devices.**
- The performance of un-catalyzed filters, such as those used in many actively regenerated devices, is not affected by fuel sulfur

Retrofit Device Verification Tests

It is essential to provide confidence in performance and durability of retrofit, diesel emission control systems.

Verification tests are recommended to assess the candidate technologies under standard protocols to demonstrate the level of emission reduction under actual applications in the field over a minimum durability period.

Diesel engines can last up to 20 to 30 years or longer. It will take many years before the existing diesel engines may be retired and be replaced with advance diesel engines that meet more stringent emissions standards.

Therefore, it is important to provide incentives for these in-use engines to be retrofitted with emission control devices or be replaced. Incentives are an effective way to encourage the use of diesel retrofit control technologies.

Incentives and Retrofit Funding

- a reduction in vehicle registration fees, taxes
- an exemption from roadside PUC inspections
- an exemption from usage / region restrictions
- clean diesel awards/publicity for fleet operators who use retrofit control technologies
- partial funding by government agencies
- Initiative schemes from OEMs

CLOSURE

- Diesel emissions from mobile sources have raised health and welfare concerns, but a number of retrofit technologies exist or are being developed that can greatly reduce emissions from diesel-powered vehicles.
- Reductions of black carbon from diesel PM offers an added benefit to reducing climate change due to its high global warming potential estimated to be up to 4500 times higher than that of CO2 on a per gram of emission basis.
- Diesel oxidation catalysts, diesel particulate filters, exhaust gas recirculation, lean NOx catalysts, lean NOx traps, selective catalytic reduction, and crankcase emissions control, have been successfully retrofitted on on-road and off-road vehicles. These technologies offer opportunities to reduce large amounts of particulate and NOx emissions and other pollutants as well, including toxic HCs.
- Diesel oxidation catalysts can reduce particulate matter emissions from 20 to 50 percent, carbon monoxide and hydrocarbons (including toxic emissions) greater than 90 percent, and substantially reduce smoke and odor from diesel engines. Fuel sulfur levels below 500 ppm (0.05% wt) are recommended. Lower sulfur levels improve the emission control performance of an oxidation catalyst.

…… CLOSURE

- Diesel particulate filter technology can reduce harmful particulate emissions by over 90 percent, reduce carbon monoxide and hydrocarbons (including toxic emissions) by over 85 percent, and significantly reduce smoke. For catalyst-based diesel particulate filters, ultra-low sulfur diesel fuel (<15 ppm sulfur) is recommended for maximum efficiency and durability.
- Both oxidation catalysts and particulate filters can be used in conjunction with biodiesel, EGR and engine management techniques to reduce diesel particulate and NOx emissions.
- Selective catalytic reduction can substantially and simultaneously reduce NOx, PM, and HC emissions.
- Lean NOx catalysts have been combined with filter systems to provide NOx reductions of 25 to 40 percent over engine-out emissions.
- When selecting a retrofit control technology, it is important to ensure that the technology is compatible with the duty cycle and according exhaust temperature pattern of the vehicle and the desired emissions reductions.
- Properly maintained vehicles and engines ensure retrofit emission control technologies will perform optimally. End users also need to follow maintenance procedures specified by the retrofit technology supplier to ensure continued performance of the retrofit device.

Re-trofitment of old-generation Heavy-duty Diesel Vehicles is a need of the hour.

Re-trofitment of old-generation Heavy-duty Diesel Vehicles is a need of the hour.

Thank you….

Retrofit Options:
Retrofit technologies have three major categories: those that alter the type of fuel used to reduce emissions, tailpipe retrofits to reduce emissions, and engine compartment modifications to reduce emissions to the cabin.

With the nationwide drive for limiting sulfur levels in diesel fuel to 50 ppm in 2017 and further to 10 ppm by 2020, emissions are expected to have significantly reduced.

This switch to cleaner fuels will allow the use of retrofit devices that otherwise would be rendered useless with higher sulfur concentrations.

For this reason, this retrofit project focuses primarily on the tailpipe modifications using Diesel Oxidation Catalysts (DOC), Diesel Particulate Filters (DPF), or Diesel Multi-Stage Filters (DMF), and engine compartment installation of Crankcase Filters (CCF).

Diesel Oxidation Catalysts enable a chemical reaction that removes approximately 20% of PM, and reduces HC by nearly 50%3. These catalysts range in price from $1,000-$2,000, depending upon catalyst composition and installation charges. DOCs can last upwards of 10 years, and require little to no maintenance once installed. Installation of a DOC can take between 1-3 hours.

Diesel Particulate Filters are capable of removing 60-90% of PM, HC, and CO when used correctly. DPFs are best suited for buses newer than 1995 in order to ensure that ideal temperatures are reached in the exhaust stream to decompose particles that accumulate in the filter. A DPF has a working life span between 7 and 15 years, and costs between $8,000-$10,000. Applicants for 20 or more buses may apply for funding for particulate filter regenerators, which must be used for all DPFs.

The third tail pipe emission reduction system is the **Diesel Multi-Stage Filter** (DMF). This muffler removes 71-75% of PM, HC, and CO. The DMF is priced between $6,000- $8,000, and requires minimal maintenance. <u>This unit is considered to be an effective compromise between the less expensive DOC and the more efficient DPF.</u>

The **<u>crankcase is the source of the vast majority of pollution</u>** that impacts students on the bus. Emissions from the engine compartment seep through cracks and openings in windows and doors to create conditions in which the particulate matter concentrations inside the bus may be many times that of ambient conditions.

Crankcase filters [illegible]educe emissions of particulate matter to the cabin by nearly 100%. Priced near $400-$700 each, [illegible]e the highest emission reductions to the cabin per dollar. The CCF must be maintained on a reg[illegible]asis by replacing the internal filter at each oil change, at a cost of approximately $50.

The CCF can be used in conjunction with DMFs, DOCs, or DPFs. Both tailpipe and crankcase retrofits are beneficial to students and the public, reducing pollutants that reach the ambient air, as well as reducing what seeps into the cabin of buses.

Particulate Control Technology Overview

Tailpipe technologies

•3 main categories: DOC(diesel oxidation catalyst), FTF(flow through filter), DPF (diesel particulate filter) •Mostly muffler replacements + ancillary

Diesel Oxidation Catalyst (DOC)

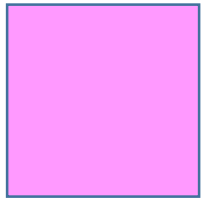
•PM reduction capability of >25% •Uses a catalytically induced reaction that converts PM, CO and Hydrocarbons to CO2 and H2O (platinum or other metals based catalyst) •Does not use a filter •Often used in combination with other devices to achieve a higher PM reduction

Flow Through Filter (FTF)

•PM reduction capability of >50% •Exhaust flows through a tortuous path (wire mesh), creating a turbulent condition –PM collides with wire mesh (impacting) •Filter medium has catalyst coating •PM that is not treated flows out with exhaust

Diesel Particulate Filter (DPF)

•PM reduction capability of > 85% •Uses a filter to "trap"PM particles in the exhaust •Two styles of filters – Passive •Uses a catalyst to reduce PM ignition temperature •PM is oxidized via exhaust heat/catalyst – Active •Uses an external source of heat to oxidize PM trapped in the filter –Fuel-fired burner –Electric heater – Fuel/catalyst induced NO2 generator



Maintenance

•Owners are responsible for –Vehicle Maintenance (impacts retrofit device) –Retrofit Maintenance •Varies by retrofit type •includes visual inspection, ash removal –General condition –Proper operation –Repair damage

Responsibility

•Owners –Select correct BART for your fleet –Fill-out, submit and maintain forms –Annual supplements –Maintain BART and vehicles •DEP –Work with owners and installers to solve problems –Maintain website for data –Review submittals – Reimbursements –Store documentation –Guidance to regulated community –Ensure compliance

- As emission requirements have incorporated the need for NOx reductions as well as PM from the in-use diesel fleet, manufacturers have developed integrated PM + NOx retrofit technologies.
- Exhaust gas recirculation (EGR) and lean NOx catalysts combined with DPFs have been retrofitted on heavy-duty diesel vehicles.
- EGR is capable of achieving about a 40% reduction in NOx emissions. EGR retrofits have seen limited application in the U.S, with approximately 1,000 engines retrofitted with EGR systems that also include a DPF.
- Retrofit EGR systems have also found a significant market penetration in Hong Kong, with over 450 systems installed.