Appendix E

Portable Diesel Engine Emission Control Technology

Portable Diesel Engine Emission Control Technologies

In this appendix to the staff report, the ARB staff provides descriptions of PM reduction emission control strategies currently available and projected to be available in the near future. Additional information on the wide variety of emission reduction options for diesel fueled engines is provided in the Diesel Risk Reduction Plan.

There are many types of control technologies available to control diesel particulate matter from portable diesel engines, such as diesel oxidation catalysts, diesel particulate filters, fuel additives and alternative diesel fuels. While most of these technologies are currently being verified by the ARB for on-road vehicles, there are some that may be verified for portable diesel engines. Currently, the diesel oxidation catalyst from Donaldson is the only control technology that has been verified for off-road engine use.

Verification of Diesel Emission Control Devices

In March 2002, the Board adopted the *Verification Procedure, Warranty and In-Use Compliance Requirements of In-Use Strategies to Control Emissions from Diesel Engines* (Verification Procedure) in support of the ARB's regulatory efforts to reduce diesel PM. The Verification Procedure establishes a process through which manufacturers of emission control equipment can demonstrate and verify the emission reduction capabilities of control technologies. Examples of emission control technologies that can be considered for verification include: diesel particulate filters, diesel oxidation catalysts, exhaust gas recirculation, selective catalytic reduction systems, fuel additives and alternative diesel fuel systems. The Verification Procedure is voluntary and applies to emission control technologies for on-road, off-road and stationary applications. A brief discussion on the Verification Procedure is provided below.

The Verification Procedure requires emission control strategy applicants to establish the emissions reduction capabilities for an emission control device, conduct a durability demonstration, conduct a field demonstration and submit results with additional information in a prescribed-format application to the ARB. The applicant verifies the product for a specific engine manufacturer, years produced, engine family and series. If after reviewing the application the ARB verifies the diesel emission control strategy, it will issue an Executive Order to the applicant stating the verified emission reduction and any conditions that must be met for the diesel emission control strategy to function properly. The Verification Procedure also requires that the applicants provide a warranty to the end-user and conduct in-use compliance testing.

The results of the Verification Procedure testing determine the control technology classification. The multi-level verification system consists of three PM reduction levels. The Verification Procedure also has provisions for verifying strategies that reduce oxides of nitrogen (NOx) emissions. Control device verifications for both PM and NOx are classified by level as listed in Table 1.

Table 1: Verification Classifications for Diesel Emission Control Strategies

Pollutant	Reduction	Classification
PM	< 25%	Not Verified
	≥ 25%	Level 1
	≥ 50 %	Level 2
	≥ 85% or ≤0.01 g/bhp-hr	Level 3
NOx	< 15%	Not Verified
	> 15%	Verified in 5% increments

Once a device has been verified, the executive order and accompanying information is posted on the ARB's web site at http://www.arb.ca.gov/diesel/verifieddevices/verdev.htm.

Diesel Oxidation Catalyst

Diesel oxidation catalyst (DOC) reduces the emissions of particulate matter (PM), carbon monoxide (CO) and gaseous reactive organic gas (ROG) from diesel engines by catalytic oxidation. The technology is only effective on the soluble organic faction of diesel PM, and therefore the overall reduction that can be achieved by a DOC is limited—the range of reduction is typically between 10 to 30 percent (Khair, 1999).

For off-road applications, the only DOC that is verified to date is the Donaldson DCM diesel oxidation catalyst muffler with 6000 series catalyst formulation plus a closed loop crankcase with the Donaldson Spiracle™ closed crankcase filtration system. This system requires the use of California Diesel fuel. The system is a Level 1, which controls diesel PM to an average of 25 percent. This system may be used in four-stroke, turbocharged diesel engines ranging from 150 horsepower (hp) to 600 hp.

Diesel Particulate filters

Diesel particulate filters (DPF) reduce diesel PM emissions through filtration. This technology is very efficient in controlling diesel PM emissions, and has been demonstrated to reduce diesel PM by over 90 percent. DPF can be categorized into several classifications: passive, active, or flow-through.

Passive DPFs use a catalytic material that allows the trapped PM to be burned-off or oxidized at a lower temperature. For the system to be successful, the engine must be operated such that the exhaust maintains a minimum temperature for a certain period of time. Otherwise, diesel PM will accumulate in the filter, eventually causing operating problems. Several passive DPFs have been verified for on-road applications. To date no DPFs have been verified for portable engines. The duty cycle for equipment must be such that the engine exhaust temperature and its duration is above the manufacturer's specifications. If temperatures are below the DPF's manufacturer's specifications, soot accumulates in the filter, increasing exhaust backpressure resulting in engine damage. Each engine should be tested to see if its duty cycle would accommodate a passive DPF.

An active DPF performs the same function as a passive DPF. The difference is that the active DPF does not use heat from the engine exhaust to oxidize the trapped PM. An active DPF is better suited for low exhaust temperatures or engines with high PM emissions. Most common methods use electrical regeneration by passing an electrical current through the filter medium, injecting fuel to provide additional heat to oxidize the trapped PM, or adding fuel-borne catalyst or other reagents to initiate regeneration. Some DPFs induce regeneration automatically on-board the vehicle or equipment when a specified back pressure is reached. Others use an indicator, such as a warning light, to alert the operator that regeneration is needed, requiring the operator to initiate the regeneration process. A number of filters are removed and regenerated externally by a regeneration station.

Flow through filter (FTF) technology is a relatively new technology for reducing diesel PM emissions. Unlike a DPF, in which only gasses can pass through the substrate, the FTF does not physically "trap" and accumulate PM. Instead, exhaust flows through a medium (such as wire mesh) that has a high density of interrupted flow channels, thus giving rise to turbulent flow conditions. DOCs have straight flow passages and laminar flow conditions. The FTFs, with its turbulent flow, allow the exhaust gases to have more contact with the catalytic surface and longer residence times. The FTF medium is typically treated with an oxidizing catalyst that is able to reduce emissions of PM, ROG, and CO, or used in conjunction with a fuel-borne catalyst. Any particles that are not oxidized with the FTF flow out with the rest of the exhaust and do not accumulate.

The filtration efficiency of an FTF is lower than that of a DPF, but the FTF is much less likely to plug under unfavorable conditions, such as high PM emissions, low exhaust temperatures and emergency circumstances. The FTF, therefore, is a candidate for use in applications that are unsuitable for DPFs.

Combinations of more than one technology are also being explored to maximize the amount of diesel PM reduction. For example, fuel-borne catalysts can be combined with any of the three main hardware technologies discussed above: DPF, FTF or DOC.

Fuel Additives

Fuel additives are essentially any substances added to the fuel. These additives can reduce the total mass of PM, with variable effects on CO, NOx and ROG production. Fuel borne catalysts (FBC) are additives to diesel fuel to aid in soot removal in DPFs by lowering the ignition temperatures of the carbonacious particles in the exhaust stream. If the ignition temperature is lower, then more of the carbonaceous portion of the exhaust stream is incinerated and not trapped in the DPF. These FBCs are to be used in conjunction with passive and active DPFs. FBC's use various metals such as cerium, platinum, copper, and iron. Most fuel additives will work with a range of sulfur concentrations as well with other fuels and other fuel additives. FBCs are not verified for portable diesel engines at this time.

Alternative Diesel Fuels

An alternative diesel fuel is a fuel that can be used in a diesel engine without modification to the engine. Alternative diesel fuels include emulsified fuels, biodiesels, Fischer-Tropsch (F-T) fuels and any combination of these fuels with regular diesel fuels.

Water emulsion diesel fuel mixes water with diesel and adds an agent to keep the fuel and water from separating. The water is suspended in the droplets within the fuel, creating a cooling effect in the combustion chamber that decreases NOx emissions. A fuel-water emulsion creates a leaner fuel to air ratio in the combustion chamber, generating less soot at combustion, thus lowering PM emissions. The major manufacturer of this fuel-water emulsion is Lubrizol Corporation, which produces PuriNOx™. According to data submitted for the ARB's fuels certification procedure (Title 13, CCR, Sections 2281, 2282 and 2284), PuriNOx™ achieved a 14 percent reduction in NOx and a 63 percent reduction in PM emissions. Similar results were found in a United States Environmental Protection Agency (U.S. EPA, 2002c) analysis. Some engine manufacturers have stated that using emulsified fuels would void the engine warrantee.

Biodiesel is a mono-alkyl ester-based oxygenated fuel made from vegetable oils, such as oilseed plants or used vegetable oils, or animal fats. Biodiesel has similar properties to petroleum-based diesel fuel, and can be blended into petroleum-based diesel fuel at 20 percent, and is called B20. Pure biodiesel is called B100. U.S. EPA recently evaluated biodiesel using publicly available data and concluded that while biodiesel and biodiesel blends reduce PM, ROG, and CO emission, NOx emissions increase, depending on the biodiesel to diesel fuel blend ratio (U.S. EPA, 2002b). As the portion of biodiesel increase, the PM, ROG and CO emissions decrease while the NOx increases. U.S. EPA predicts that B20 will reduce fuel economy by one to two percent. Biodiesel costs more than double the cost of conventional diesel.

Fischer-Tropsch fuels have been used to some degree since the 1920s. Today, these fuels are being used in South Africa to power buses, trucks and taxicabs. Fischer-Tropsch technology converts coal, natural gas and low-value refinery products into a high-value, clean burning fuel. This fuel is interchangeable with conventional diesel fuel and can be blended with diesel fuel in any ratio with little or no modification (U.S. EPA, 2002a). Fischer-Tropsch fuels do have emissions reduction benefits. A study showed that PM emissions were reduced by 30 percent and NOx emissions by 5 percent (CEC, 2002). No alternative diesel fuels have been verified by the ARB for portable diesel engines.

Although there may be feasible control technology options developed or being developed, only one has been verified to date by the ARB for portable diesel engines. As more companies submit their products under the Verification Procedure, it is expected that more control technology options will be available for portable engine owners and operators in the future.