APPENDIX C

EXHAUST AFTERTREATMENT TECHNOLOGY

Issued by the California Air Resources Board
April 2001

EXHAUST AFTERTREATMENT TECHNOLOGY

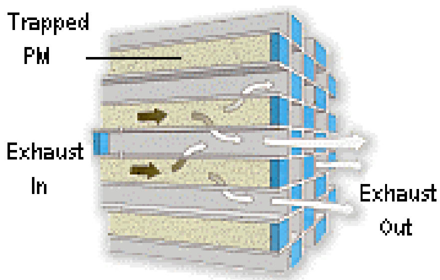
In 1998, following an exhaustive 10-year scientific assessment process, the Air Resources Board (ARB) identified particulate matter (PM) from diesel-fueled engines as a toxic air contaminant (TAC). Diesel particulates are small, generally less 2.5 microns in diameter. These particles are complex substances typically consisting of a carbon core with adsorbed hydrocarbons, sulfates, water and inorganic materials. Diesel PM emissions are estimated to be responsible for about 70 percent of the total ambient air toxics risk. In addition to these general risks, diesel PM can also present elevated localized or near-source exposures. A significant near-source exposure group is school children. The Lower-Emission School Bus Program proposes to reduce this potential risk by replacing high-polluting school buses with new buses, and by installing special exhaust filters on remaining older buses.

Special exhaust filters, as aftertreatment or retrofit devices are available to reduce emissions from the diesel-powered school buses. These devices have been available for many years and have a proven track record of durability and effectiveness in heavy duty vehicles. The Lower Emission School Bus Program proposes to fund ARB certified aftertreatment devices that reduce diesel particulate matter (PM) emissions by at least 85%. Most of these devices are similar to current automobile catalytic converters and can be easily installed on existing buses. However, to perform effectively these devices require the use of low sulfur fuel. Use of diesel aftertreatment devices has been limited because high levels of sulfur are detrimental to their operation. The increased availability of low sulfur diesel fuel now makes widespread use of these devices practical.

The most commonly available aftertreatment device is a diesel particulate filter (DPF). Installation involves placing the DPF in the vehicles' exhaust system. In many cases the DPF replaces the existing engine muffler. The following section discusses filters suitable for this program.

A. Diesel Particulate Filters

Today, there are over 7,500 diesel particulate filters (DPF) units in use worldwide. Some of these systems have exceeded 375,000 miles of in-field use. The product is currently being used in eight heavy-duty vehicle fleets in southern California and at the New York Metropolitan Transportation Authority. The product is commercially available and being demonstrated in California school buses. In total, the technology has accumulated hundreds of millions of miles. DPF technology can achieve up to, and in some cases exceed, 85 percent reduction in PM. The filters may also reduce emissions of carbon monoxide, hydrocarbons, and in some cases oxides of nitrogen. The graphic below illustrates one type of DPF.



A typical system consists of a filter positioned in the exhaust stream designed to collect particulate emissions while allowing the exhaust gases to pass through the system. Over time, particulate matter generated by a diesel engine is sufficient to fill up and plug a filter. Therefore, a means of disposing of the trapped particulate must be provided. The most promising means of disposal is to oxidize (or burn) the trapped particulate during regular vehicle operations, thus regenerating the filter.

Two basic types of particulate filters are used: passive and active. Most passive diesel particulate filters (DPF) remove PM by collecting particles and oxidizing them during vehicle use. The oxidation process is referred to as regeneration. Passive DPFs typically rely on a precious metal catalyst contained in the filter to allow regeneration at common engine exhaust temperatures. In active filters the regeneration temperature is achieved by means of an external heat source. This typically involves an electric or other heat source to increase oxidation in the filter. There are many techniques used to facilitate regeneration. However, most DPF filters are passive self-regenerating filter systems using precious metals, like automobile catalytic converters. Usually, these DPF devices collect particulate matter and oxidize it when the exhaust temperatures are above 530°F. DPF systems do not appear to cause any additional engine wear or effect normal vehicle maintenance. However, DPF devices may require periodic maintenance to remove ash caused by motor oil combustion residues.

Several mature DPF technologies have emerged. A side by side school bus demonstration of Johnson Matthey's CRT™ diesel particulate filter and Engelhard's DPX™ catalytic soot filter is currently underway. A system manufactured by Ceryx is also being tested in school buses. All systems require the use of low-sulfur diesel fuel, i.e., fuel with sulfur less than 15 parts per million (ppm).

Johnson Matthey's CRT™ device combines a platinum catalyst and a filter element. The catalyst oxidizes NO to NO_2 and uses the produced NO_2 as an oxidant to remove the PM trapped in the filter. This method removes PM and a small percentage of exhaust NOx. Engelhard's DPX™ device uses a different catalyst system that does not significantly affect exhaust NOx. Ceryx Incorporated's QuadCAT™ device is designed to replace the conventional muffler/silencer on a diesel engine. The QuadCAT™ is designed to reduce PM and oxides of nitrogen (NOx).

Independent research programs are underway to study the effects of different levels of sulfur in diesel fuel. In one such program in southern California, Detroit Diesel Corporation, Johnson Matthey, and Engelhard will demonstrate use of British Petroleum's new diesel fuel containing virtually no sulfur. This fuel may enable catalysts and particulate filters to operate more efficiently with increased durability. Johnson Matthey's CRT™ has demonstrated PM reductions greater than 90 percent by using ultra-low sulfur fuel.

A number of filter materials have been developed. Currently, ceramic monoliths, fiber wound cartridges, silica carbide and paper filters have been used commercially. The collection efficiencies of these filters range from 50 to over 90 percent.[1] All of these materials achieve high efficiencies; however, development work continues with the materials to (1) optimize the filter collection efficiency while reducing back pressure, (2) improve the regeneration process, and (3) improve the mechanical strength of the filter designs.

The exhaust temperature of a diesel school bus engine is not always high enough to initiate regeneration. A number of techniques are used to lower the regeneration temperatures found in bus exhaust. For example, in the CRT™ and DPX™ devices the filter element is coated with a catalyst. The application of a catalyst reduces the required regeneration temperature. Other techniques include the use of fuel-borne catalysts, electrical heating elements, or combustion of atomized fuel in the exhaust system to increase the temperature of the exhaust gas to start regeneration.

Diesel particulate filters are typically optimized for the particular vehicle application. This ensures the maximum control efficiency possible, while minimizing or eliminating adverse effects of the system on the engine or vehicle performance. Use of catalyzed DPFs also greatly reduces odors typically exhibited in diesel exhaust. A slight fuel economy penalty may be experienced with DPFs. This is usually attributed to the backpressure caused by a plugged DPF. Some forms of DPF regeneration involve the use of fuel burners, and if these methods are used, a 5 to 10% fuel economy penalty could be experienced. For example, Ceryx Incorporated's QuadCAT™ device uses fuel to assist in regeneration.

Filter systems do not appear to cause any additional engine wear or affect vehicle maintenance. Maintenance of the system itself should be minimal, because manufacturers are designing systems to minimize maintenance requirements during the useful life of the system.

Demonstration programs using first generation DPFs were conducted during the 1980's and into the early 1990's. Some of these systems were complex and reliability was an issue. Subsequently, manufacturers began development and

[1] Emission Control Retrofit of Diesel-Fueled Vehicles, MECA, March 2000

commercialization of second-generation systems. These simpler and more reliable systems can easily achieve PM reductions greater than 85 percent. In Europe diesel vehicles retrofitted with DPFs are offered commercially. Sweden's Clean Cities program has resulted in the commercialization of DPFs in urban transit buses. Passive filters have been installed in over 10,000 trucks and buses. Some of these vehicles have accumulated over 300,000 miles since being retrofitted. Sweden's very low sulfur diesel has enabled the use of the DPFs. Heavy-duty trucks in Germany, Finland, and France are also being retrofitted with filters. Other demonstration programs are being carried out in Taiwan and Hong Kong.

Diesel particulate filters have been used commercially in off-road equipment since 1986. The types of equipment retrofitted include mining equipment, material handling equipment, forklifts, street sweepers and utility vehicles. Germany and Austria have mandatory retrofit requirements for underground mining equipment. In the United States filters are being used in the Big Dig project in Boston. Construction equipment such as earthmovers and front loaders were retrofitted with particulate filters.

Currently, the South Coast AQMD and the ARB are conducting a demonstration program in which about 60 school buses have been retrofitted with particulate filters (the ARB is providing testing support).

B. Need for Low Sulfur Fuel

California established specifications for diesel fuel in 1990 (CARB diesel). These specifications included a 500-ppm limit on sulfur content. The typical sulfur level in CARB diesel fuel is 120 ppm. Certification of DPF devices requires the use of CARB diesel that contains 15 ppm or less sulfur. Each DPF technology has somewhat different response to sulfur levels in diesel fuel. All manufacturers agree that the sulfur levels below 15 ppm ensure optimum emission control and DPF durability.

Staff expects the low sulfur diesel fuel to cost 3 to 5 cents more per gallon than current CARB diesel. During the ARB the Transit Bus Fleet Rule development, several California refiners stated their intent to provide low sulfur diesel fuel to transit bus fleets. These refineries have the capability to produce sufficient quantities of low sulfur fuel for statewide requirements.

School districts in urban areas should be able to obtain low sulfur fuel at reasonable cost. It is unclear whether rural areas would be able to obtain low sulfur fuel at the expected cost of 3 to 5 cents per gallon above current CARB diesel. Depending on the volumes involved it may not be cost effective to deliver low sulfur diesel fuel to remote areas. Availability of low-sulfur fuel should not be a concern given the expected demand from transit and the school bus fleets expected to participate in the retrofit program.