Appendix B. Diesel Engine Emission Control Technology Review

There is a wide variety of technologies for controlling emissions of PM and NOx from in-use diesel engines. The following discussion briefly reviews the more common technologies in use today, and those which will likely play an important role in meeting ARB's emission reduction goals.

A. Diesel Oxidation Catalyst

A diesel oxidation catalyst (DOC) is one of the simplest aftertreatment devices available and is used in both new engine and retrofit applications. Typically using a very light loading of platinum catalyst, it is able to oxidize compounds that exist in the gas phase while in a diesel engine's exhaust system. These include carbon monoxide (CO) and, more importantly, many of the hydrocarbon (HC) species that condense into droplets and form the soluble organic fraction (SOF) of PM upon leaving the exhaust system and entering the atmosphere. By oxidizing most of the SOF in the exhaust, DOCs are typically able to reduce PM emissions by about 25 percent (Level 1). However, they do not reduce the solid soot particles in PM by any appreciable amount. Because of this limitation, DOC technology will not play a significant role in meeting California's goal of significant PM emission reductions from diesel engines.

B. Diesel Particulate Filters

A diesel particulate filter (DPF) is another type of aftertreatment device that is far more effective at reducing emissions of PM than the DOC. Its key component is a filter medium, typically a porous ceramic or sintered metal material, which permits gases in the exhaust to pass through but traps the PM. DPFs are very efficient in reducing PM emissions, typically achieving PM reductions in excess of 85 percent (Level 3). A DPF requires a means to periodically regenerate the filter (i.e., burn off the accumulated PM), and is often categorized by the nature of this means as either a passive or active DPF.

1. Passive Diesel Particulate Filters

A passive DPF is one in which a catalytic material, typically a platinum group metal, is applied to the filter itself or some other substrate upstream of the filter. The catalyst lowers the temperature at which trapped PM will oxidize to levels that are often reached in diesel exhaust, generally 250 to 400 ^{o}C, depending on the vehicle's duty cycle. No additional source of energy is required for regeneration, hence the term "passive". Most verified passive DPFs require exhaust temperatures of at least 225 to 280 ^{o}C for about 25 to 50 percent of the vehicle's duty cycle.

The simplicity of the passive DPF is both its primary selling point and its main limitation. Not requiring any special controls or external energy source, the passive DPF has simple construction and operation, and tends to be less expensive than more sophisticated control systems. To regenerate properly, however, passive DPFs require certain minimum exhaust temperatures. They are also sensitive to an engine's PM emission rate. Unfavorable changes in either parameter can cause the filter to plug with PM and create operational problems for the engine. For these reasons, candidate vehicles need to be carefully screened before passive DPFs are installed.

2. Active Diesel Particulate Filters

Unlike passive DPFs, active DPFs use a source of energy for regeneration beyond the heat in the exhaust stream itself. Active DPF systems can be regenerated electrically, with fuel burners, or with the aid of additional fuel injection to increase exhaust gas temperature. Some active DPFs induce regeneration automatically on-board the vehicle when a specified backpressure is reached. Others simply indicate to the operator when regeneration is needed, and require the operator to initiate the regeneration process. Some active systems collect and store diesel PM over the course of a full day or shift and are regenerated at the end of the day with the vehicle or equipment shut off. A number of systems are designed such that the filters can be removed and regenerated externally at a “regeneration station.”

Because regeneration is not dependent on the heat of the exhaust, active DPFs have a much broader range of application and a much lower probability of plugging than passive DPFs. However, this advantage is often accompanied by greater system complexity and cost.

C. Flow-Through Filter

Flow-through filter (FTF) technology is a form of aftertreatment that achieves PM reductions somewhere in between a DOC and a DPF. There are several very different FTF designs, but they tend to share the characteristic that they do not trap and accumulate PM like a DPF. Instead, FTFs have a medium (such as a wire mesh) that forces the exhaust into a complex flow pattern that gives rise to turbulent flow conditions or in some cases a partial trapping of PM. The medium is typically treated with an oxidizing catalyst that is able to reduce emissions of PM, HC, and CO. The particles that are not oxidized within the FTF flow out with the rest of the exhaust and tend not to accumulate. FTF performance can be highly variable and sensitive to exhaust temperature, but is normally consistent with the Level 1 or 2 classification.

D. Fuel Additives

The Procedure broadly defines fuel additives to be substances that are present in-cylinder during combustion for any of a number of different purposes, such as decreasing emissions or assisting in the operation of another diesel emission control system. One common type of fuel additive, known as a “fuel borne catalyst” (FBC), is routinely used in several countries in Europe to assist in the regeneration of DPFs. FBCs are metallic in nature (e.g., cerium, iron, and platinum) and are added in low concentrations to diesel fuel. Particles of the FBC get associated with soot particles during the combustion process and significantly lower the soot combustion temperature. FBCs can be used in conjunction with both passive and active DPFs.

E. NOx Control Technologies

Technology to control NOx emissions from in-use diesel engines has grown in its importance as a means to helping California meet its air quality goals. A number of the most common NOx control systems are briefly described below.

1. Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) is an effective engine-based method for reducing NOx emissions that has been used in many new engine applications for the past five years. A valve connected to the exhaust system allows a controlled portion of spent combustion gases to circulate back into the intake system where it mixes with pre-combustion air. The exhaust serves as a diluent to lower the in-cylinder oxygen concentration and also to increase the heat capacity of the air/fuel mixture. This reduces peak combustion temperature and the rate of combustion, thus reducing NOx emissions. Though much less prevalent than EGR systems for new engines, EGR retrofits are in use both in Europe and in the United States. One such system which is combined with a passive DPF is currently verified for certain on-road engines in California. Typical NOx reductions achieved by EGR retrofits are about 40 to 50 percent.

2. Selective Catalytic Reduction Systems

Selective catalytic reduction (SCR) systems are a form of aftertreatment technology that uses a reductant, typically urea, to convert NOx to nitrogen and oxygen over a catalyst. A precise amount of reductant is injected into the exhaust upstream of the catalyst. If the reductant is well mixed with the exhaust and the exhaust temperature is adequate, (typically between 250 and 450 ^{o}C) an SCR system can achieve NOx reductions on the order of 50 to 90 percent. SCR technology is already mature in stationary applications and is beginning to emerge as a NOx control solution for in-use mobile sources.

One of the challenges facing SCR technology is the practical need to ensure that the end-user maintains a continuous supply of reductant. Urea is currently not as commercially available as diesel fuel. Also, if urea is not present in the SCR unit, it will not cause any intrinsic engine or vehicle operational problems. SCR retrofit manufacturers must therefore devise strategies to induce end-users to refill reductant tanks before they run out. Techniques such as not allowing the engine to restart or reducing the engine’s power output are potential means of ensuring end-user compliance.

3. Lean-NOx Catalyst Systems

Another aftertreatment-based NOx control technology is referred to as the lean-NOx catalyst (LNC). Similar in principle to an SCR system, an LNC system relies on injection of a reductant upstream of the catalyst to reduce NOx emissions. The reductant, in this case, is not urea but rather some form of hydrocarbon, typically diesel fuel. The NOx reductions achievable by LNC technology are sensitive to the exhaust temperature and type of hydrocarbon used, but are typically in the neighborhood of 20 to 30 percent.