

## **Frequently Asked Questions on Diesel Emissions and Diesel-Emission Control Technologies**

### **1. What types of emissions are produced by diesel engines?**

Like any other internal-combustion engine, diesel engines convert the chemical energy contained in diesel fuel into mechanical power. Diesel fuel is injected under pressure into the engine cylinder, where it mixes with air and combustion occurs. Compared to gasoline-powered engines, the lean nature of the diesel-air mixture results in a cooler combustion environment with smaller volumes of carbon monoxide (CO) and hydrocarbons (HC). However, diesel engines do produce relatively high levels of gaseous emissions of nitrogen oxides (NO<sub>x</sub>) and particulate emissions, often referred to as diesel particulate matter (DPM).

DPM is a complex aggregate of materials that includes:

- Dry carbon particles (or soot) and inorganic oxides (primarily sulfates)
- A soluble organic fraction that results from incomplete combustion of diesel fuel and engine lubricating oils and tends to adsorb or condense onto the carbon particles, and
- A gaseous component consisting mainly of CO, NO<sub>x</sub> and sulfur dioxide (SO<sub>2</sub>).

Diesel particulate emissions tend to be very fine, with an average particle size of 0.04–1 micron, and form a complex, respirable aerosol mixture. Implicated in a range of worker illnesses, these pollutants are particularly troublesome when diesel-powered engines are operated in enclosed spaces, such as underground mines, construction zones, tunnels or warehouses.

While the total concentration of pollutants in exhaust from today's diesel engines often amounts to just a fraction of a percent, this pollution source still needs to be effectively managed through better engine design and the use of emission-control technologies that are designed specifically for this complex mix of airborne pollutants.

### **2. How are diesel emissions regulated?**

The principal toxic gas compounds found in diesel exhaust include carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO<sub>2</sub>), and sulfur dioxide (SO<sub>2</sub>). The toxic characteristics of these compounds have been studied for years and are relatively well understood. Diesel emissions also contain other compounds that may also pose a health threat to humans, including polynuclear aromatic hydrocarbons (PAHs), nitro-PAHs, aldehydes, and other hydrocarbons and their derivatives.

Diesel emissions are subject to strict regulations worldwide, and have become the focus of ongoing developments in diesel emission-control technologies. In general, regulations related to diesel emissions tend to fall into three categories:

1. *Tailpipe-emission regulations* specify the maximum amount of pollutants allowed in the exhaust gases from a diesel engine. In the United States, the Environmental Protection Agency (EPA) sets these standards, while similar regulatory authorities set their own standards worldwide. The duty to comply with tailpipe-emission regulations rests on diesel engine manufacturers, who must receive certification that their equipment meets applicable emissions thresholds before such equipment can be sold commercially. For example, EPA requires that diesel particulate matter (DPM) emissions from all heavy-duty engines intended for highway use be below 0.1 g/bhp-hr.
2. *Ambient-air-quality standards* specify the maximum concentration of air contaminants that are allowed in the workplace (typically as permissible exposure limits, or PELs), and thus impact the use of diesel engines in confined spaces. In the U.S., these regulations are set by the Occupational Safety and Health Administration (OSHA) or the Mining Safety and Health Administration (MSHA), and by similar regulatory authorities worldwide. The duty to comply with ambient-air-quality standards rests with the end user (for instance, the mine or warehouse operator), who must make sure that the proper pollution-control equipment is in place to handle site-specific emissions.
3. *State regulations* sometimes set more stringent tail-pipe standards than the federal regulations. The main driver often is the state's requirement to meet federal air quality standards. To better understand how these regulations may affect you and your applications, Engelhard suggests that you check with your local or state environmental agency for specific regulations in your area.

### **3. How can diesel emissions be controlled?**

Diesel emissions are controlled in two ways: at the source, through ongoing modification to engine design, and/or through the use of add-on controls that treat the diesel exhaust.

Add-on controls include both diesel traps, which rely on filters to physically remove diesel particulate matter from the exhaust stream, and catalytic pollution-control systems, which destroy many of the pollutants in the diesel exhaust stream by promoting chemical changes that convert unwanted compounds into more-benign chemical species.

### **4. What are diesel-oxidation catalysts?**

Diesel-oxidation catalysts are used to promote the oxidation of many of the gas-phase pollutants found in diesel exhaust. Such systems convert pollutants such as carbon monoxide,

hydrocarbons, the soluble organic fraction of diesel particulates, and several hydrocarbon derivatives, including aldehydes and polynuclear aromatic hydrocarbons (PAHs), into simpler, less toxic compounds, such as carbon dioxide and water.

Diesel-oxidation catalyst formulations require a careful balance to maximize certain chemical reactions, while minimizing others. For instance, today's diesel-oxidation catalysts are designed to maximize the oxidation of hydrocarbons and other gas-phase pollutants, while minimizing the formation of secondary sulfate particulates during the oxidation of SO<sub>2</sub> (so as not to increase the total particulate emissions load).

As with many other catalytic air-pollution-control systems, diesel-oxidation catalysts are typically configured by depositing the active catalyst material as a "washcoat" on a rugged substrate or carrier. That substrate is typically made from cordierite (a synthetic ceramic) and configured as a monolithic honeycomb. The honeycomb design combines high surface area with good thermal shock resistance and high mechanical strength, and imposes relatively low pressure-drop, even at high exhaust-gas velocities.

Catalyst formulations vary by vendor, and the exact nature of these proprietary blends tends to be fiercely guarded by their developers. In general, oxidation catalysts for diesel emissions rely on precise blends of precious metals, such as platinum, palladium and rhodium, oxides of silica, titania and zirconia, and base metals such as vanadium, molybdenum and niobium. Substituting base metals for platinum can help to reduce sulfate formation while maintaining the conversion of hydrocarbons, carbon monoxide, and the soluble organic fraction of the exhaust stream.

## **5. What are particulate filters?**

To improve the removal of diesel particulate emissions, catalyst manufacturers have been working to develop diesel particulate filters that operate in conjunction with catalytic converters. While catalytic converters tend to focus on the gaseous portion of the exhaust stream, particulate filters combine surface-type and deep-bed filtration mechanisms to collect particulate matter from the engine exhaust stream during operation.

The challenge in developing commercially viable traps or filters for diesel engines is to come up with designs that minimize clogging (and the pressure drop that would result from a clogged filter), and that can be thermally regenerated, either periodically or continuously, to remove the accumulated particulate material.

To improve low-temperature regeneration of the particulate filter, several catalyst vendors have developed a catalyzed diesel particulate filter (CDPF), which incorporates a catalyst that lowers the soot-combustion temperature. The catalyst allows the filter to regenerate itself by promoting oxidation of the accumulated soot under exhaust temperatures that are experienced during regular engine operation. To date, several catalyzed diesel particulate filters have been

developed, using both noble and base metal formulations, and have found early commercial application in underground mining and other stationary engine applications.

## **6. What about NO<sub>x</sub>? (SCR systems)**

Unlike HC, CO and PM, NO<sub>x</sub> cannot be removed through oxidation; it must be reduced. This is accomplished by combining residual HC and CO with NO<sub>x</sub> to form nitrogen, carbon dioxide and water. However, since the diesel and some natural gas engines are lean-burn engines, the excess amount of HC and CO are not available for this process and must be introduced from an outside source.

For most lean burn engines this process requires the use of a selective catalytic reduction (SCR) system. In the past SCR systems were applied to large stationary sources such as turbines and industrial boilers. Recently, however, SCR systems have been applied to diesel and natural gas engines in the US.

In simple terms, an SCR system introduces a reductant, typically urea or aqueous ammonia, into the exhaust stream of the engine prior to a catalyst bed. The reductant when introduced creates a stoichiometric environment allowing NO<sub>x</sub> to be reduced on the catalyst. The SCR system can be effective up to 99% against NO<sub>x</sub> and has been primarily used on engines in the power industry.