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Diesel Under Pressure

By Joseph Alper

In the history of internal combustion engines, two names stand out: Nicholas Otto and Rudolf Diesel. Otto's gasoline-powered engine, patented in 1876, now drives most cars and small trucks. Diesel's compression-ignition engine, patented in 1893, powers most heavy-duty trucks, ships, buses, and farm and construction equipment.

Diesel designed his engine to be an improvement over Otto's power plant, and in many respects it was. Diesel's engine gets 15-100% better fuel economy and emits lower amounts of carbon monoxide and smog-inducing hydrocarbons. The diesel engine is also more durable and is capable of running several hundred thousand miles between overhauls (see "Rudolf Diesel's Engine," *Chem Matters*, December 1990).

But diesel engines have one major problem—their exhaust. Diesels emit microscopic carbon particles, even when their exhaust appears clean. A diesel-powered car, for example, emits some 50 grams of invisible soot particles per hour and, in many cities, the air is already overloaded with particles from many other sources. Furthermore, diesel exhaust contains carcinogens. Scientists at the U.S. Environmental Protection Agency (EPA), have concluded that among all noxious materials discharged into the atmosphere, only roofing tar fumes and coke oven emissions exceed diesel exhaust in their potential for causing cancer.

Hot process

A diesel engine gets its power from burning a mixture of fuel and air in an enclosed cylinder fitted with a movable piston. Air is drawn into a cylinder and then compressed by the piston. As the piston moves upward on its compression stroke, the temperature of the air in the cylinder increases dramatically—so much so that when the fuel is injected into the cylinder, it ignites spontaneously. As the fuel burns, the resulting heat and pressure move the piston with sufficient force to rotate the crankshaft. The rotary motion then moves the truck or generates electricity.

The diesel process leads to its superior fuel economy—its high operating temperature produces more power from a gallon of fuel. Unfortunately, the same process also generates nitrogen oxides and soot. Nitrogen oxides, abbreviated NOx, form when the nitrogen and oxygen in air react at the diesel engine's high temperatures. NOx is a significant pollutant because it forms smog, corrodes buildings, weakens plants, and irritates human lungs and eyes. It is possible to modify the engine to lower the operating temperature, but then the fuel economy—the diesel's primary advantage—goes down as well.

Then there is the problem of soot. No internal combustion engine burns 100% of its fuel, and the unburned fuel appears in the exhaust as a pollutant. Otto (gasoline) engines emit gaseous hydrocarbons, whereas diesel engines emit particles of soot. Soot forms because the diesel fuel is not thoroughly mixed with the air when it starts burning. The regions within the cylinder that are lean (have excess air) burn the fuel completely to carbon dioxide and water. However, in the regions that are rich (have insufficient air) the fuel is not completely oxidized and the unburned carbon forms solid particles—soot.

Even a well-tuned diesel engine emits 30 to 100 times more soot than a comparable gasoline engine equipped with a catalytic converter. Diesel soot particles are coated with a sticky organic layer that makes them good at fouling buildings. Soot is also smelly and corrosive, and contributes to the atmospheric haze seen in many cities.

The problem is more than aesthetic. The diesel particles are so small that they can travel deep into the lungs. Normally, your lungs get rid of foreign objects by way of the so-called mucociliary escalator, a series of cells covered with tiny hair-like projections that sweep offending materials out of the lungs and into the throat. From there, the material gets swallowed and excreted through the digestive system. Diesel particles, however, are so tiny that many of them evade this defense system. The diesel soot piles up in the alveoli, the small sacs in which your lungs exchange carbon dioxide for oxygen. With enough exposure to diesel exhaust over enough time, the accumulated soot can cause respiratory diseases such as emphysema.

Worse yet, the sticky organic material on the soot contains about 200 different substances, many of which are known carcinogens. Others are converted into carcinogens in the lungs by chemical reactions that occur naturally in cells. The organic compounds leach slowly from the porous particles, which means that the soot acts as a reservoir for the steady release of carcinogens into the lungs. Not surprisingly, laboratory animals that inhale diluted diesel exhaust develop lung cancer more often than those that breathe clean air or even diluted gasoline engine exhaust. Other experiments suggest that diesel exhaust may make other cancer-causing substances, such as cigarette smoke, more potent.

Railroaded

The case against diesel exhaust does not rest solely on animal studies, however. Scientists have compared the health of groups of people who were continually exposed to diesel exhaust for a number of years with carefully matched groups of people who were not. The most thorough survey was done by researchers at Harvard Medical School, who examined the cause of death of more than 17,000 railroad workers. The men who had worked on diesel-powered locomotives constituted the "exposed" group. The remaining men, who had worked in other jobs, or had worked on locomotives powered by coal or electricity, made up the "control" group. The results showed that men in the exposed group were nearly one-and-a-half times as likely to develop lung cancer as the control group.

What do diesel engine manufacturers say about these findings? "Certainly, we are concerned about the possible health problems associated with diesel emissions, and engine manufacturers are developing new engine technology that will make significant impacts on engine emissions," said Greg Walker, a spokesperson for the Motor Vehicle Manufacturers Association, the industry trade group. Dr. Jaroslav Vostal, chief biomedical researcher at General Motors, dismissed the Harvard study as meaningless.

EPA, however, has had plenty to say on the matter. Martha Casey, agency spokesperson, said, "EPA's position is that diesel exhaust is toxic, and, while we've never quite come out and said officially that diesel exhaust causes cancer, the data certainly make it look that way." Regulations that took effect January 1, 1991, require new trucks to reduce particulate emissions by nearly 60% and new buses to reduce particulate emissions by more than 80%. By 1994, trucks will have to meet the more stringent bus standards.

The one problem with such regulations is that they will not affect air quality until the next century. For example, most buses on the road today were built before any regulations were in place, and because diesel bus engines last about 15 years, it will be some time before the older polluters are replaced by cleaner buses. But recent research on diesel combustion may help.

Sulfur core

Studies conducted at the Southwest Research Institute in San Antonio, TX, found that a large proportion of diesel particles form around a nucleus rich in sulfur. Ridding diesel fuel of sulfur contaminants prevents these nucleating particles from forming during combustion, and as a result, particulate matter is cut substantially. In fact, reducing the sulfur content of diesel fuel cuts particulate emissions to less than the 1991 truck standard without any changes in the engines themselves. On the basis of these studies, the Motor Vehicle Manufacturers Association submitted to EPA a proposal to reduce the amount of sulfur in diesel fuel, and EPA responded by making the proposal law (effective October 1990). Oil refiners must now remove the sulfur from diesel fuel, a move that EPA believes will have a significant impact on both particulate and sulfur dioxide emissions. "This is a big step in cleaning up diesel emissions," said EPA's Casey, "for it will positively affect both new and old engines." Walker adds that this step "will certainly help us meet the tougher emission standards, so it's something (we) are really in favor of."

Another way to improve diesel emissions quickly is to change fuels. In Southern California, some public buses are burning compressed natural gas instead of diesel fuel. These buses produce few, if any, of the major carcinogens found in diesel exhaust. In addition, the buses emit almost no soot and several thousand times less NOx. Best yet, all this comes without any loss of engine performance. The major drawback of compressed natural gas is the expense of modifying engines to burn the fuel and of changing fuel tanks. Also, the larger tanks required may make natural gas unsuitable for ships and railroad locomotives.

In spite of its serious environmental problems there is still a great deal of life left in Rudolf Diesel's invention. If engineers can clean up its noxious exhaust, the diesel engine may go on to a second hundred years of driving trucks, pushing ships, and saving fuel.

CAPTIONS

CAUTION The government has determined that the exhaust from this bus can be hazardous. Its diesel engine emits not only many common pollutants (hydrocarbons, NOx, sulfates), but also especially troublesome carbon particles—soot.

Diesel soot, magnified 10,000 times. Researchers at the Environmental Protection Agency passed the exhaust from a diesel engine through a filter for one minute, then made this photograph with a scanning electron microscope. The large structures are Teflon-coated fibers that make up the filter. The accumulated soot particles appear as a fuzzy mass over the fibers.

BIOGRAPHY

Joseph Alper, 1987 winner of the American Chemical Society's Grady-Stack Award for Interpreting Chemistry for the Public, wrote "Killing For Oil," Chem Matters, October 1988.

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