ADEQ
Arizona Department
of Environmental Quality

Common Sense Approach To Diesel Emissions

Student Study Guide

TM-16-04

Introduction

This program provides technical and background information that will familiarize today's diagnostic technicians with:

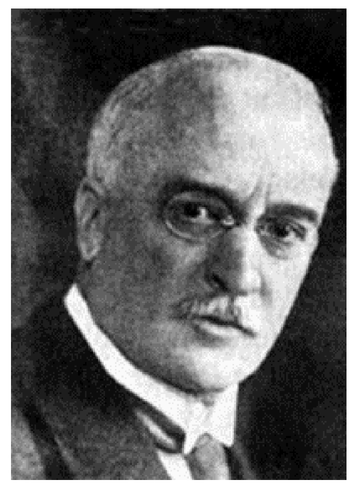
- Diesel emissions formation
- Diesel engine management technologies
- Emissions testing techniques
- Emissions problem diagnostics

This program covers diagnostic information for solving emissions problems found on both light-duty and heavy-duty diesel vehicles. This program will cover both mechanically controlled and electronically-controlled diesel engine management systems.

In 1892, Inventor Rudolf Diesel filed for a patent at the Imperial Patent Office in Germany. Within a year he was granted a patent for "Working Methods and Design for Combustion Engines…a new efficient thermal engine". His vision was an engine in which air was compressed to such a degree that it would cause an extreme rise in the temperature. When fuel is injected into the piston chamber with this air, the fuel is ignited by the high temperature of the air, exploding it, and forcing the piston down. In 1897 the first diesel engine suitable for practical use operated at an efficiency of 75%. This was a vast increase over the steam engine, which only operated at an efficiency of 12%, and the internal combustion engine of the time that operated only at an efficiency of 25%.

Diesel's greatest achievement was at the 1900 Paris Exposition where the diesel engine was presented the Grand Prix (the highest honor). This engine amazed all in attendance since it was fueled by 100% peanut oil. In 1912 he stated: "The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries that use it" also "The use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time."

In 1898, Rudolph Diesel was granted a US patent for "an internal combustion engine", the Diesel engine, and the first US production of the Diesel began. The Diesel engines of today are refined and improved versions of Rudolph Diesel's original concept.



Rudolph Diesel

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Diesel Emissions

Diesel Engine Operation

Power, Fuel Economy & Low Emissions

Electronic Control of Diesel Emissions

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Diesel Emissions

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Diesel Emission Advantages

A diesel engine can run much leaner**; therefore, it produces lower levels of Hydrocarbons and Carbon Monoxide than a comparable gasoline-fueled engine.**

Diesel Emission Disadvantages

Due to the nature of the combustion process and the lower refinement of fuel, diesel engines produce much higher levels of Oxides of Nitrogen and Particulate Matter.

Pollutants
Motor vehicles are a major source of the pollutants that contribute to the formation of smog, as well as other environmental and health problems. These pollutants are:

NOx - Nitrogen Oxides

VOCs - Volatile Organic Compounds (primarily HCs and partially oxidized HCs)

PM10 - Particulate Matter of 10 microns in diameter (and smaller)

CO - Carbon Monoxide

SOx - Sulphur Oxides

CO2 - Carbon Dioxide

Ozone Formation

NOx and VOCs are of special importance. In the presence of light and heat, NOx and VOCs react to form ozone, a primary element of smog. Smog is a mixture of gaseous, solid and liquid pollutants that is harmful to human health, plant life and building materials. Ozone occurs naturally in the upper atmosphere as a gas that shields the earth from ultraviolet radiation. **At ground level, Ozone causes inflammation of the lungs and reduces their functional capability and resistance to infection. There is no "safe" or "acceptable" level of ozone in breathable air. Detrimental health effects linked to Ozone can occur at any concentration.** People with heart and lung problems are particularly vulnerable to the harmful health effects of ozone.

Particulate Matter Formation

The term "Particulate Matter" (PM) refers to a mixture of solid particles and liquid droplets in the air. PM10 is particulate matter that is 10 microns in diameter or smaller (including fine particles). The origin of coarse PM10 (PM that is between 10 and 2.5 microns in diameter) includes road dust and dust from agricultural activity **and can come from a wide variety of sources, including windblown dust, construction activity and grinding operations**..

PM2.5 can form from SOx, NOx and VOCs in the atmosphere after the initial combustion of fuel. In simple terms PM is a form of carbon caused by incomplete combustion of diesel fuel. **Sources for PM2.5 (PM that is 2.5 microns or smaller) include fuel combustion in motor vehicles** (especially diesel trucks and buses)**, power plants, factories, wood-burning stoves and fireplaces.**

Most vehicle-related PM10 comes from diesel engines. **The vast majority takes the form of PM2.5.** Diesel-powered vehicles are also a major source of NOx.

Health Effects

Particulate matter varies widely in its origin, size and chemical/physical composition. Larger particles pose little health risk. They are heavy enough to fall quickly to Earth, thus reducing their chances of being inhaled. **Fine particles (2.5 microns and smaller), pose a threat to human health.** Among susceptible people (such as the elderly and those with cardiopulmonary disease), PM can worsen existing health problems.

In addition, PM can bring on lung problems in people with no previous history of lung disease. Due to the small size, PM can remain suspended in air for an extended period. This increases the chance of it being inhaled or transported by wind over great distances. PM can penetrate deeply into the lungs, where it can remain and cause both temporary breathing difficulties and permanent lung disease.

PM that originates from diesel fuel combustion presents particular health risks. PM from diesel engines is typically smaller than 0.1 micron. Particles this size are known as ultra-fine (or "nano") particles. They are able to penetrate deep within the air-carrying cells of the lungs. Ultra-fine particles from diesel engines consist of a number of substances, some of which are known threats to human health. Many are suspected carcinogens.

Diesel PM consists of carbon particles that may adhere to one another and/or collect other contaminants on their surface. Diesel PM may also contain acidic particles formed from sulphuric acid present in the exhaust stream.

Polynuclear Aromatic Hydrocarbons (PAHs) are among the contaminants that adhere to the surface of the carbon particles. Some PAHs are proven human carcinogens.

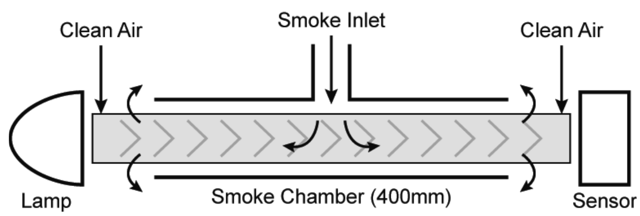
Researchers have linked particulate matter, particularly fine particles, to be linked to such health effects as:

Asthma attacks
Coughing and difficulty in breathing
Chronic bronchitis
Decreased lung capacity
Lowered resistance to infection
Premature death

Diesel Emissions Testing-Opacity Meter

An opacity meter is a smoke density, measuring device. Light is directed through a chamber and an optical sensor measures the intensity of light received through the smoke sample.

Fig. 1-1



The principle behind opacity meter measuring is recording the amount of light passing through a sample of the exhaust gas. Absence of smoke in the measuring cell means zero opacity (optical density). Complete shading of the measuring cell (non-transparent gas) means 100% opacity. If the smoke only allows 70% of the light to reach the receptor the meter will read 30% opacity. The smoke column in the cell is measured by means of an optical system, using a green LED as a light source. A photodiode is used as a detector, which is heated to 30° C. The opacity meter tests opacity for 7 seconds with sampling time interval of 20 ms. Then the measured samples are mathematically evaluated. This procedure repeats as many times as required until the measured values complete the conditions of the test requirement. Resulting smoke is calculated as arithmetic readouts.

Maintenance of the Meter

Conduct a visual check of optical lens and connections.
Use a soft moistened cloth or swab to remove soot and residue.
Do not use any cleaning liquids! (Unless recommended by the equipment manufacturer)

NOTES:

STUDY QUESTIONS

DIESEL EMISSIONS

Use the following questions to help check your understanding of the material presented. Either circle the correct answer or fill in the blanks as necessary. Then check your answers in "Answer Key" at the back of the book.

1. PM from diesel engines is most often typically smaller than _______________.

A. 10 microns

B. 2.5 microns

C. 0.1 micron

D. None of the above

2. When it pertains to emissions, one of the disadvantages of a diesel engine is:

A. diesel engines require changing engines several times during the life cycle of the vehicle

B. HC and CO_2 emissions increase so less of these pollutants are admitted to the atmosphere.

C. diesel engines produce much higher levels of NO_X and particulate matter to the atmosphere.

D. diesel engines produce much higher HC and CO levels than a gasoline engine.

3. The health effect linked to Particulate Matter (PM), particularly fine particles are___.

A. asthma attacks and chronic bronchitis

B. coughing and difficulty breathing

C. lowered resistance to infection and premature death

D. All of the above

4. One of the advantages of a diesel engine over a gasoline engine when it pertains to emissions is:

A. a diesel engine does not create pollutants

B. a diesel engine only creates NOx, and we do not test diesel engines for NOx

C. a diesel engine produces lower levels of HC and CO than a gasoline engine

D. a diesel engine produces lower levels of all pollutants than a gasoline engine

5. At what size/microns can Particulate Matter (PM) penetrate deeply into the lungs and pose a serious threat to human health.

A. 10 microns

B. 5 microns

C. 2.5 microns

D. 20 microns

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Diesel Engine Operation

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Four Stroke Diesel Engine Operations

Intake:
During the intake stroke of a diesel engine, air enters the cylinders through the intake manifold. The vacuum (area of lower pressure) that is created by the downward motion of the piston draws air past the open intake valve into the cylinder. **"Volumetric efficiency" refers to the percentage of air drawn into any cylinder**. The lack of intake air restriction in the design makes diesel engines highly volumetrically efficient.

Compression:
Once the cylinder has reached BDC and has fully filled with the air charge, the intake valve closes. This traps the contents of the cylinder in the bore. **The piston then begins its upward travel, compressing the air volume to 1/20th to 1/25th of its original volume.** This quick compression increases both the pressure and temperature of the trapped air. Temperatures and pressures vary depending on the design of the particular engine.

Power Stroke:
Just before the beginning of the power stroke, highly atomized fuel vapor enters the combustion or pre-combustion chamber. The fuel mist begins to ignite in the high temperature environment. The resulting explosion of fuel in the cylinder applies force to the top of the piston, forcing it downward and rotating the crankshaft. This action produces the desired power. **The amount of power produced by the cylinder relates directly to timing and the amount of fuel delivered during this process.**

Exhaust:
As the piston again reaches BDC of the power stroke, the exhaust valve opens. As the piston travels back upward under the power of another cylinder's power stroke, it expels the previously burned air/fuel mixture. This creates room for the cylinder to refill with a fresh volume of air for the next combustion event.

Quality and Variables:
Variations anywhere during the process can and will result in changes in the emissions that are output from the engine. Lack of available intake air will cause an overly rich mixture, resulting in high levels of HC, CO and PM in the exhaust. Excessive backpressure or exhaust restriction will prevent the cylinders from properly evacuating, again resulting in overly rich conditions due to lack of oxygen in the cylinder. Incorrect timing will vary emissions levels toward either rich or lean, depending on the degree and direction of the error.

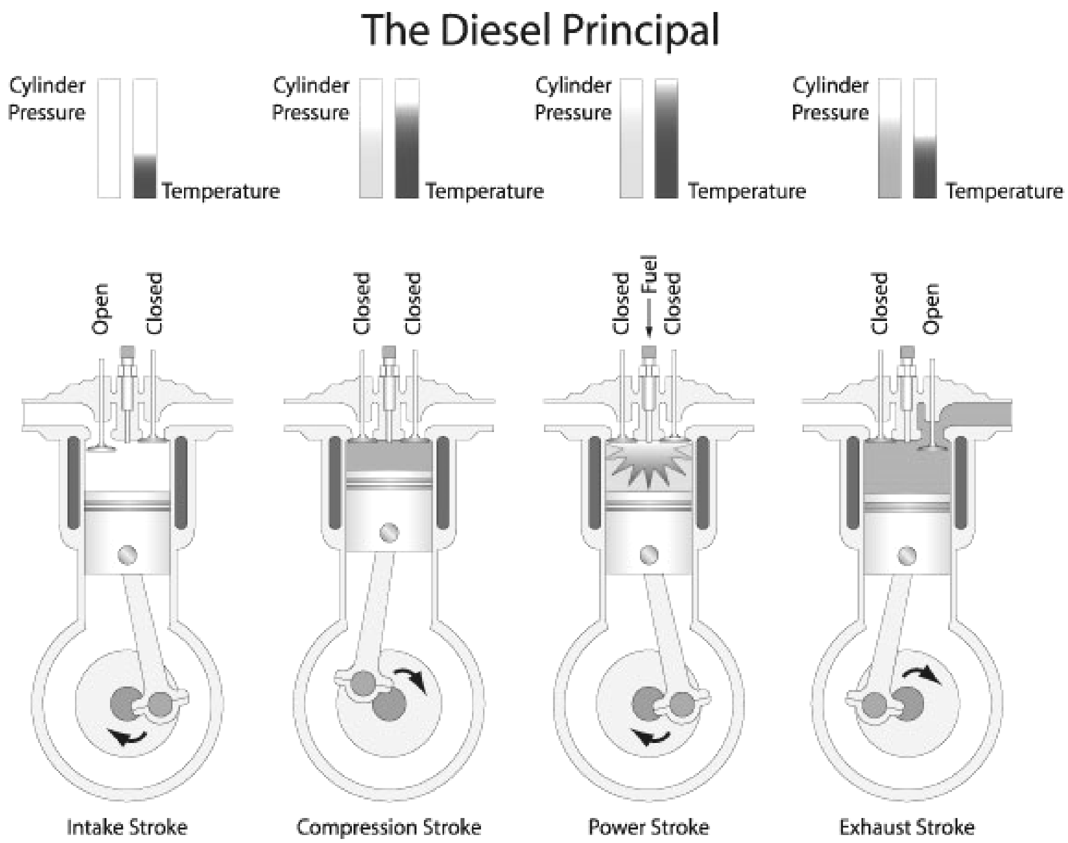

The Diesel Principal
Cylinder Pressure
Temperature
Cylinder Pressure
Temperature
Cylinder Pressure
Temperature
Cylinder Pressure
Temperature
Open
Closed
Closed
Closed
Closed
Fuel
Closed
Closed
Open
Intake Stroke
Compression Stroke
Power Stroke
Exhaust Stroke

Fig. 2-1

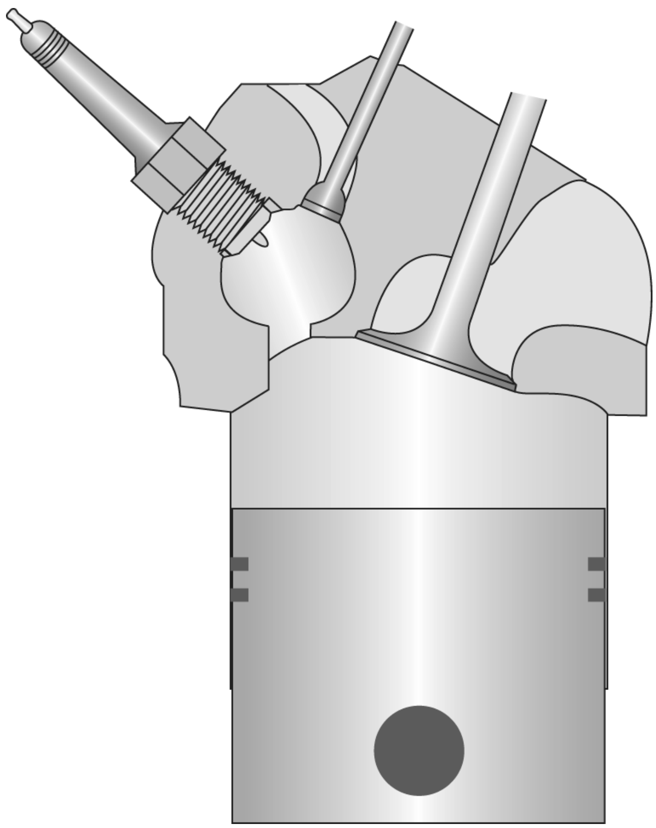
NOTES:

Diesel Combustion Systems

Pre-Chambers (Indirect Injection-IDI Systems)

A pre-chamber is a small, auxiliary combustion chamber, connected to the main chamber by a narrow orifice. Fuel injected into the pre-chamber ignites there. This causes hot gases to expand into the main chamber (cylinder).

Fig. 2-2



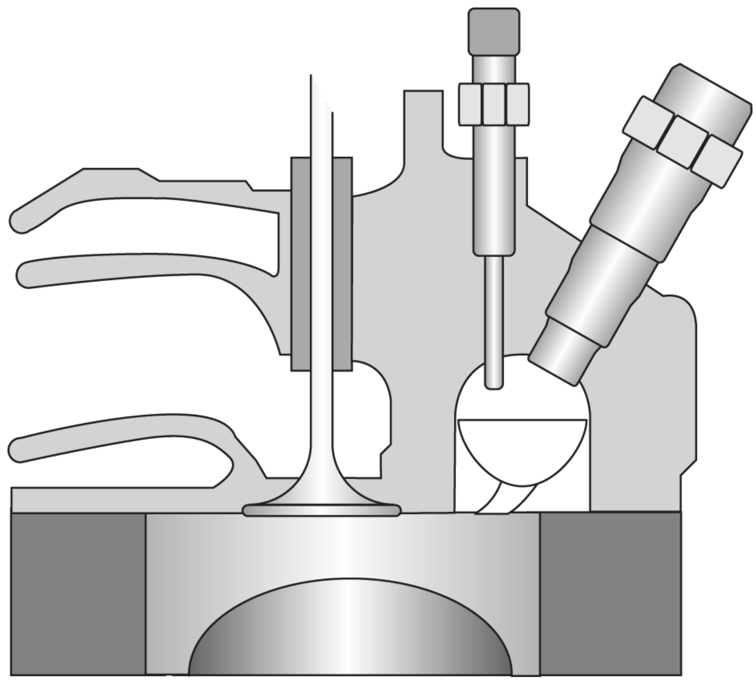
The pre-chamber will generally equal approximately 20 - 30% of the cylinder's TDC volume. Although these systems are more emission-friendly, they generally are not the most efficient with regard to power creation.

Used predominantly in diesel car applications.

Swirl Chambers (Indirect Injection-IDI Systems)

The Swirl (or "turbulence") chamber system bears similarity to the pre-combustion chamber. These systems use a separate chamber for both fuel mixture and the beginning of the combustion process. Swirl chambers are generally larger than pre-combustion chambers (about 50 - 75% of the cylinder's TDC volume). Swirl chambers allow for lesser atomization of fuel, while still providing highly efficient combustion. This reduces particulate emissions while increasing power.

Fig. 2-3



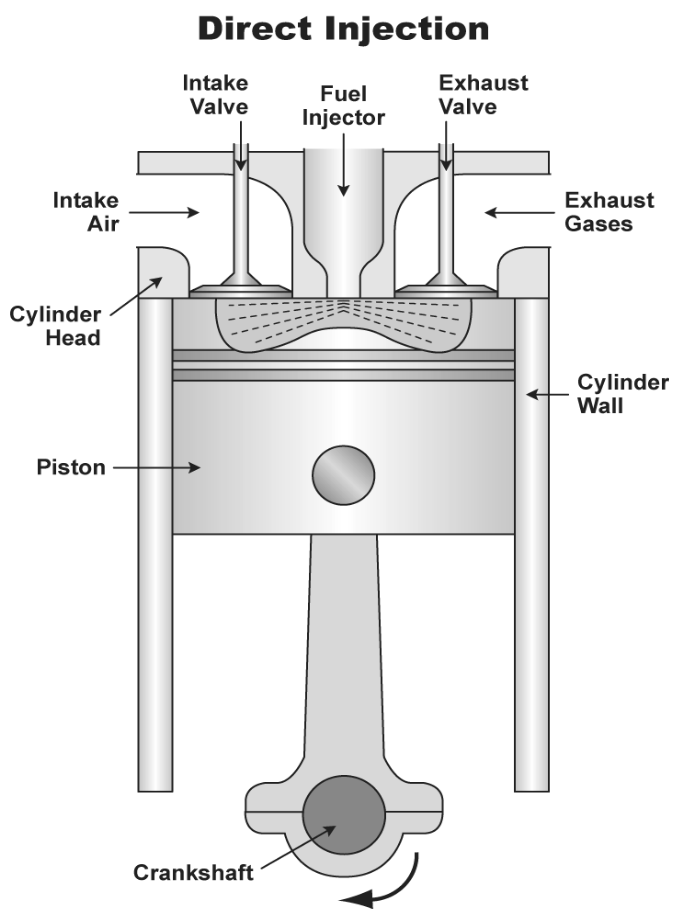
Some swirl combustion chambers have a larger rim around the outside of the piston and a more compact combustion chamber or bowl. The swirl inside the combustion chamber reduces particulate emissions.

Used on generator engines (various manufacturers), Land Rover, Hyundai's Industrial engines, Mitsubishi, Daewoo, Daimler-Benz A-class engines.

Direct Injection

In diesel engines featuring direct injection, the combustion chamber does not divide. The system injects fuel directly into the cylinder.

Fig. 2-4



In the world of heavy-duty trucks, direct injection is by far the most-common combustion system. These systems generally operate at a higher fuel pressure to achieve maximum fuel atomization. **The direct injection system achieves greater efficiency by enhancing fuel mixing through internal chamber turbulence (created by the design of the piston crown).**

STUDY QUESTIONS

DIESEL ENGINE OPERATION

1. **The most common type of combustion chamber for a heavy-duty truck is ______________________________.**

   A. Pre-Chamber B. Direct Injection Chamber

   C. Swirl Chamber D. None of the above

2. **TRUE or FALSE - Indirect injection systems use a separate chamber for both fueling and the beginning of the combustion process.**

3. **TRUE or FALSE - The combustion chamber does NOT divide in the direct injection chamber design.**

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Power, Fuel Economy & Low Emissions

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Improving Power Means Increasing Flow

One of the most effective ways to get more power out of an engine is to increase the amount of both air and fuel that the engine can burn. One way to do this is to either add cylinders or make the existing cylinders bigger. Sometimes these changes may not be practical. In such cases, **increasing the volume of air and fuel moved through the engine requires other means**. These may include:

Turbochargers

Superchargers

Intercoolers

Turbochargers are a type of forced induction system. They compress the air flowing into the engine. The advantage of compressing the air lies in the ability to squeeze more air into a cylinder. More air means that more fuel can be added. Therefore, you get more power from each explosion in each cylinder. A turbocharged engine produces more power overall than the same engine without turbo charging. This can significantly improve the power-to-weight ratio for the engine.

In order to achieve the boost, the turbocharger uses the exhaust flow from the engine to spin a turbine, which in turn spins an air pump. The turbine in the turbocharger spins at speeds of up to 150,000 revolutions per minute (RPM). Since the turbocharger is located in line with the flow of exhaust gas, the turbine temperatures run very high.

Turbochargers allow an engine to burn more fuel and air by packing more of each into the existing cylinder volume. **The typical boost provided by a turbocharger is 6 to 8 pounds per square inch (PSI).** Since normal atmospheric pressure is 14.7 PSI at sea level, this process forces approximately 50% more air into the engine. However, the process is not perfectly efficient, **so a 30 - 40% improvement is the norm in most cases**.

This inefficiency stems from the fact that the power required to spin the turbine does not come freely. The turbine is placed in the line of the exhaust flow which increases restriction in the exhaust. Therefore, on the exhaust stroke, the engine must act against higher backpressure. This takes away a certain amount of power from any cylinders that are firing at the same time.

The turbocharger also improves efficiency at higher altitudes, where the air is less dense. Normal engines will experience reduced power at high altitudes because each stroke of the piston results in a smaller mass of air introduced into the engine. A turbocharged engine may also experience reduced power, but the reduction will be less dramatic because the thinner air is easier for the turbocharger to pump.

The turbocharger is bolted to the exhaust manifold of the engine. The exhaust from the cylinders spins the turbine. The turbine connects to the compressor by way of a shaft located between the air filter and the intake manifold. The compressor pressurizes the air going into each cylinder.

The exhaust from the cylinders passes through the turbine blades, causing the turbine to spin. The more exhaust that goes through the blades, the faster they spin. On the other end of the shaft attached to the turbine, the compressor pumps air into the cylinders. The compressor is a type of centrifugal pump. It draws air in at the center of its blades and flings it outward as it spins. In order to handle speeds of up to 150,000 RPM, the turbine shaft requires very careful support. Most bearings would explode at speeds like this, so most turbochargers use a fluid bearing. This type of bearing supports the shaft on a thin layer of oil constantly pumped around the shaft. This serves two purposes: It cools the shaft (as well as other turbocharger parts) and allows the shaft to spin without significant friction.

Fig. 3-1 Turbocharger

One of the main problems encountered with turbochargers is that they do not provide an immediate power boost under acceleration. The turbine takes a moment to reach speed before producing boost. This creates a lag that is felt under acceleration. Once the turbo gets moving, the engine surges with power. **One way to decrease this turbo lag is to reduce the inertia of the rotating parts.** This requires reducing their weight, to allow the turbine and compressor to accelerate quickly and provide boost sooner.

One sure way to reduce the inertia of the turbine and compressor is to make the turbocharger smaller. A small turbocharger will provide boost more quickly and at lower engine speeds. However, this type of system may not be able to provide much boost at higher engine speeds, when a very large volume of air is entering the engine. This type of system also runs the danger of spinning too quickly at higher engine speeds, as a great deal of exhaust passes through the turbine.

Most turbochargers have a Wastegate. This allows the use of a smaller turbocharger to reduce lag, yet prevents the turbine from spinning too quickly at high engine speeds. The wastegate is a valve that allows the exhaust to bypass the turbine blades. If pressure gets too high, it could indicate that the turbine is spinning too quickly, so the wastegate allows the blades to slow down. The wastegate senses boost pressure and bypasses some of the exhaust flow around the turbine blades, if necessary.

Some turbochargers use ball bearings instead of fluid bearings to support the turbine shaft. These, however, are not typical ball bearings. These are super-precise bearings made of advanced materials to handle the speeds and temperatures of the turbocharger. They allow the turbine shaft to spin with less friction than the fluid bearings used in most turbochargers. They also allow the system to use a slightly smaller, lighter shaft. This helps the turbocharger accelerate more quickly, further reducing turbo lag. Ceramic turbine blades are lighter than the steel blades used in most turbochargers. Again, this allows the turbine to spin up to speed faster, which reduces turbo lag.

Some engines use two turbochargers of different sizes. The smaller one spins up to speed very quickly, reducing lag. The larger unit takes over at higher engine speeds to provide more boost. Some engines use Variable Geometry Turbochargers that are designed to allow the effective aspect ratio to be altered as conditions change, for reduction of turbo lag at low speeds.

When air is compressed, it heats up. When air heats up, it expands. Therefore, some of the pressure increase from a turbocharger comes as the result of heating the air before it goes into the engine. In order to increase the power of the engine, the goal is to get more air molecules into the cylinder, not necessarily greater air pressure.

An intercooler or charge air cooler is an additional component that looks something like a radiator, except air passes through the inside as well as the outside of the intercooler. The intake air passes through sealed passageways inside the cooler, while the engine cooling fan blows air from outside across the cooling fins.

The intercooler further increases the power of the engine by cooling the pressurized air coming out of the compressor before it goes into the engine. This means that if the turbocharger is operating at a boost of 7 PSI, the intercooler system will provide 7 PSI of cooler air. This denser air contains more air molecules than warmer air.

A supercharger is another type of device that compresses the combustion air or the air/fuel mixture before it enters the engine cylinder. In a typical supercharger system, the engine itself will drive the unit through a system of gears, a belt drive or an electrical motor.

Fuel Injection (Overview)

System Types:

Pump-In-Line Systems:
Each injector uses a single cam-driven piston pump, with timing and duration determined mechanically.

Rotary Pump Systems:
These are similar to Pump-In-Line systems, but use a single pump to provide fuel pressure that a rotary valve then distributes to each injector.

Unit Injectors:
The pump and injector combine to form a single unit driven by the camshaft.

Electronic Unit Injectors:
These employ the same concept as unit injectors, but control injector timing electronically.

Hydraulic Electronic Unit Injectors:
On these systems, high-pressure hydraulic oil provides the majority of the compression energy, governed by a combination of electronic and hydraulic controls.

Common Rail Systems:
All injectors link to a common reservoir at high pressure, while solenoids control each injector electronically.

Notes:

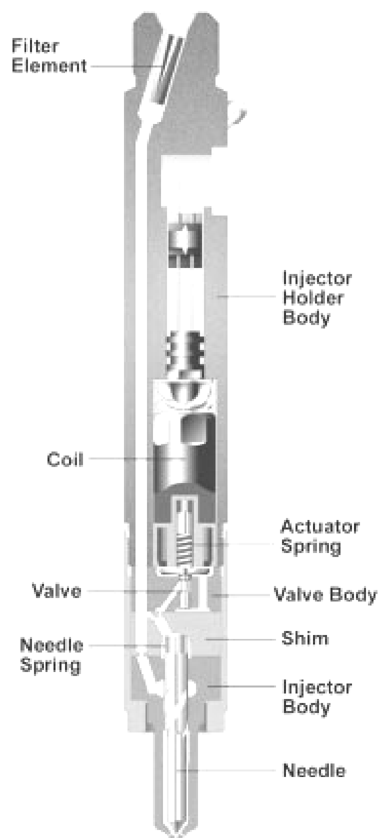
Fuel Management (Mechanical)

Pump-In-Line Injection Systems

The pump in-line diesel fuel injection system is similar to a carburetor in that this technology remained in use for a long period and is now giving way to systems offering better performance. In a pump in line system, a camshaft-driven pump determines fuel injection pressure and timing.

The primary disadvantages of pump in line systems are variation of injection pressure relative to engine speed and difficulty in generating high injection pressures at low speed. Both of these factors are necessary in order to reduce emissions in modern engines.

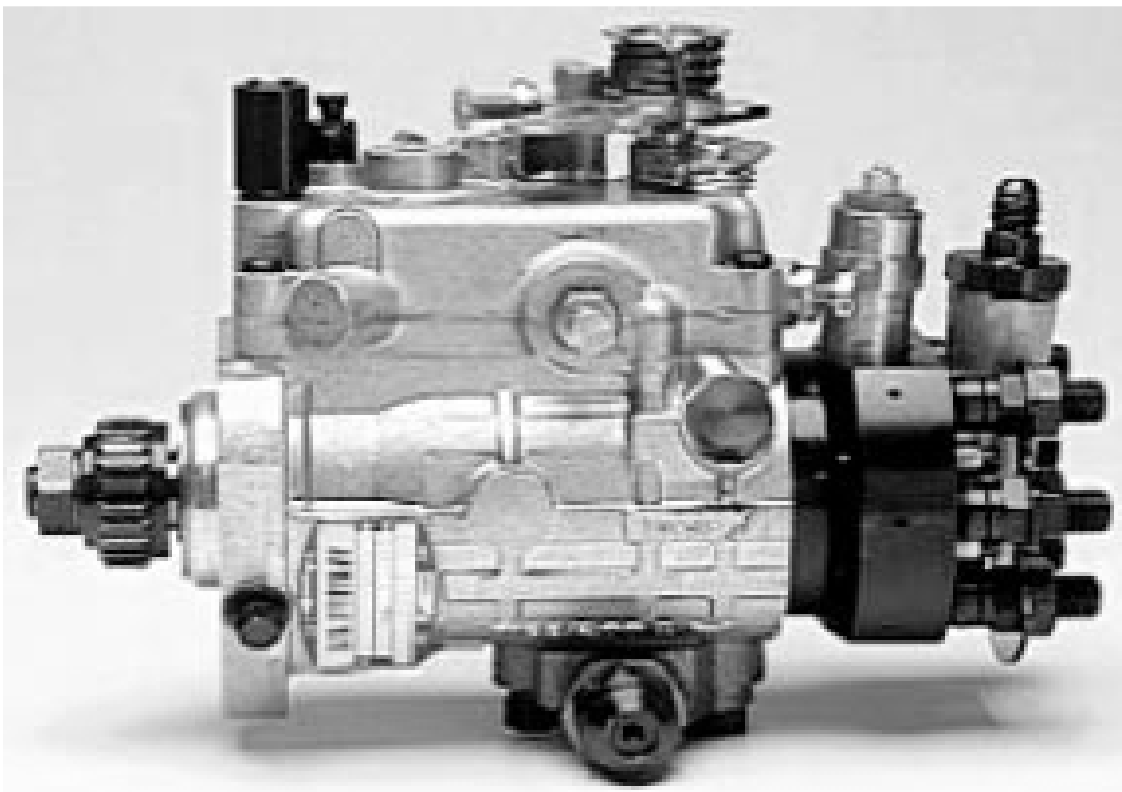
Fig. 3-3



Rotary Pump Systems

Rotary pumps, particularly electronically or hydraulically controlled rotary pumps offer a major improvement over pump-In-Line systems. In this system**, a single pumping element replaces the individual pumps. A rotary valve then distributes fuel to the proper cylinder. In addition to a reduction in the number of components, the rotary pump system also insures that fuel delivery to each cylinder is identical. This simplifies system calibration.**

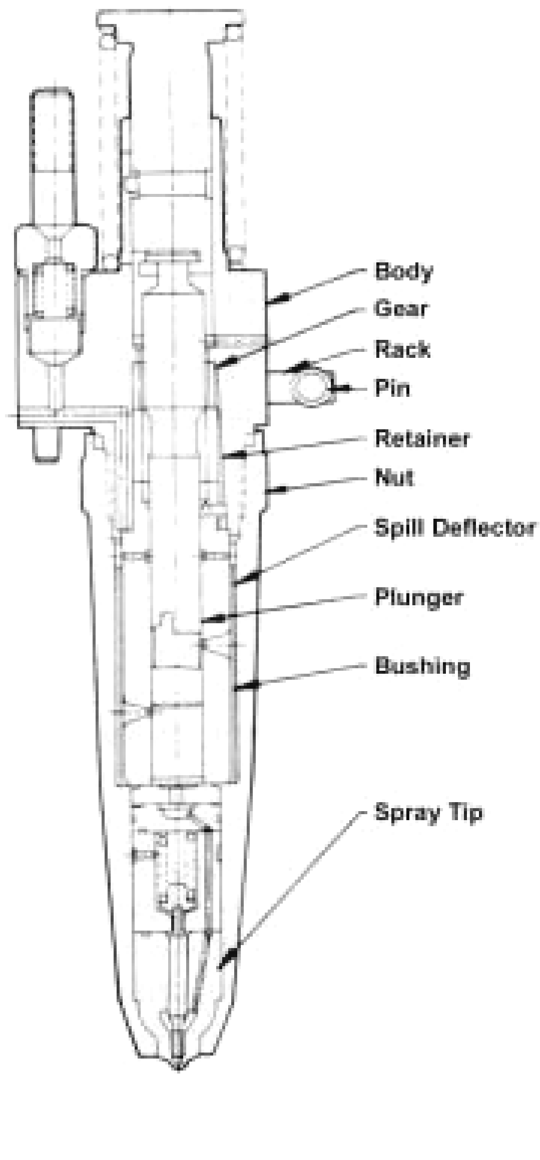
Fig. 3-4



Unit Injector Systems

Many large-bore diesel engines use unit injectors. These combine the pump and injector into a single camshaft-driven unit. The combination pump/injector design eliminates the pressure oscillations found on pump in line systems. However, the use of a lobe on the camshaft to drive the injector pump makes variation of timing with engine speed impossible.

Fig. 3-5



Electronic Unit Injectors

An advance on both pump-in-line and mechanical unit injectors is the electronic unit injection system found in many heavy-duty truck applications. Electronic Unit Injector (EUI) systems use camshaft power to pressurize the fuel, while an electronically controlled solenoid determines the injection timing and duration. Since the high-pressure fuel is only available during a fixed cam period, full control of injection parameters over a wide range of engine speeds and loads is still not possible with these units.

Fig. 3-6

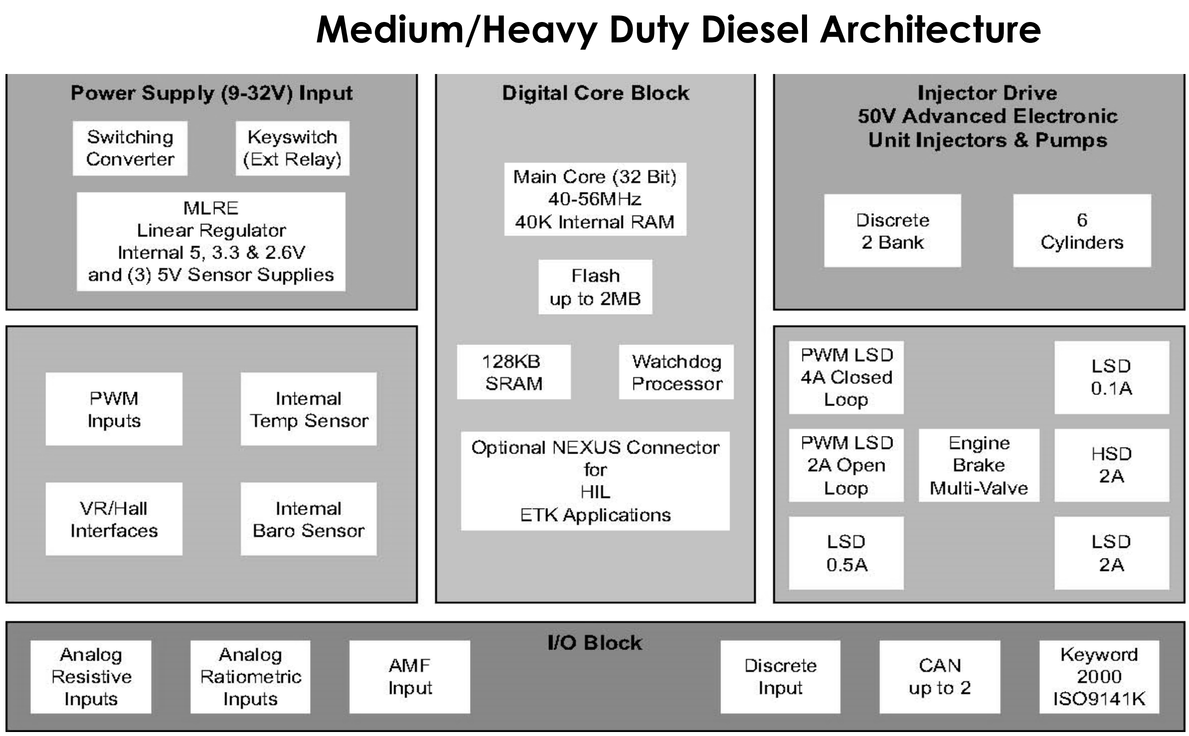
NOTES:

Fuel Management (Electronic)

Electronic Direct Injection

Electronic direct injection evenly distributes fuel from injector to injector throughout the system. This creates more power with each injector pulse than indirect injection. On such systems, pressure generation functions independent from engine speed.

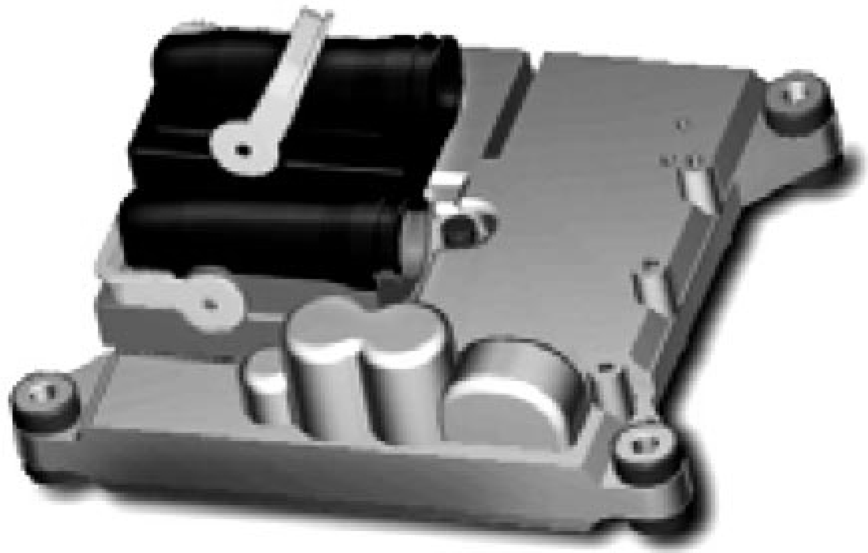
Fig. 3-7



The electronic direct injection system is programmable for optimal performance over the entire engine speed range. This allows for new levels of fuel efficiency, emissions and driving comfort under all conditions. The low-pressure pump draws fuel from the tank through the Electronic Driver Unit (EDU). The fuel then cools the electronics, which, in turn, actuate solenoid valves in each injector.

The EDU works with the Engine Control Module (ECM) to provide a strong, precise signal for each cylinder's combustion. The ECM also controls pressure in the fuel rail to ensure that it will be correct for precise fuel delivery.

Fig. 3-8



From the EDU, fuel passes through an engine-mounted fuel filter. This filter has a water sensor, water separator and fuel heater. If necessary, the heater warms the fuel to 57° F to prevent any waxing of the fuel. The fuel then goes to the high-pressure pump. If the ECM and EDU function as the "brain" of the system, the high-pressure pump is the "heart." The high-pressure pump sends fuel to the rails at variably controlled pressures of up to 23,000 PSI. From there, the system distributes fuel to the injectors at each cylinder.

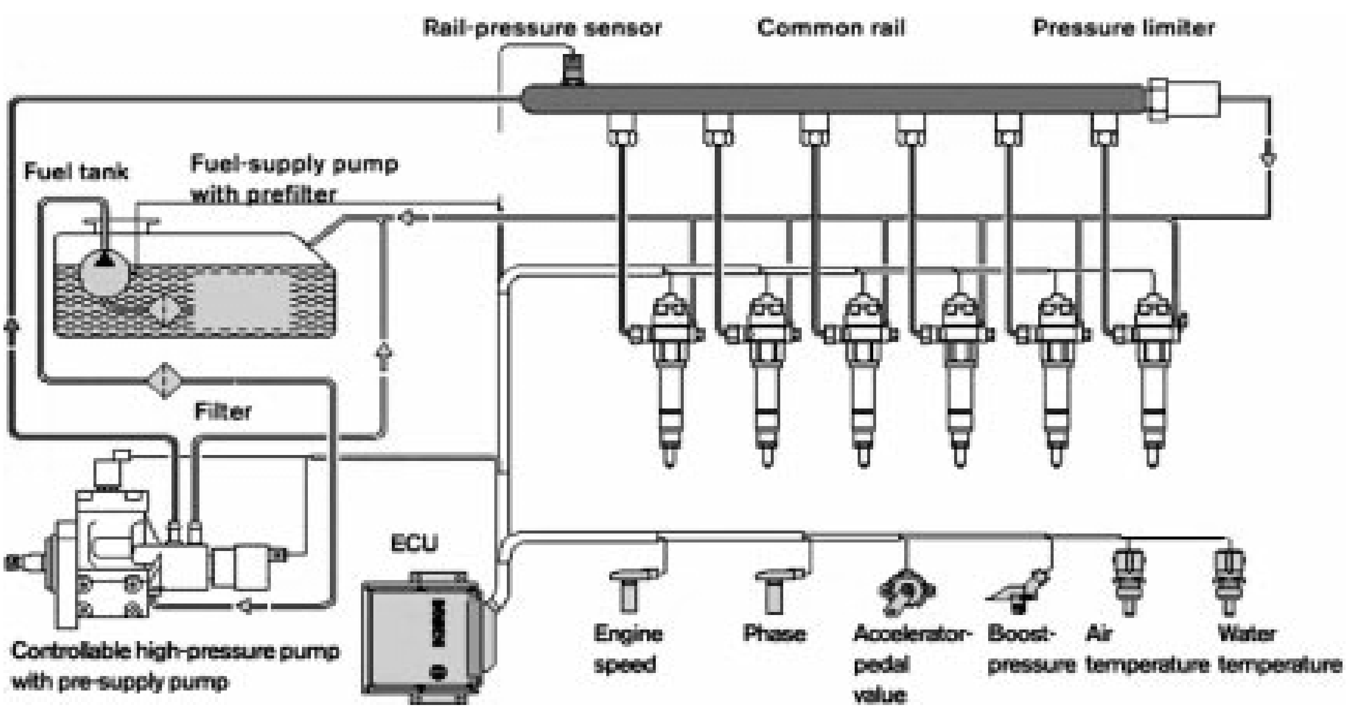
With a constant pressure feed, the injector can now open, remain open or close as directed by the ECM and EDU. The systems interpret various sensor inputs in order to achieve effective combustion for the conditions present. Typically located in the cylinder head, the injector features a custom-designed spray pattern matching the combustion chamber. This enables the most efficient combustion, improved fuel efficiency, lower emissions and reduced thermal loss.

Common Rail Systems

One major shortcoming of all the systems described thus far is the variation in achievable injection pressure brought about by engine speed. Due to nature of mechanical pumps, only less-than-peak pressure is available at low-to-medium speed range. The availability of high injection pressure at low engine speed serves to improve low-end torque, fuel economy and emissions.

A common rail fuel system provides high injection pressures throughout the engine operating range by feeding a continuous flow of high-pressure fluid to each injector. The configuration of a common rail system very closely matches a port-injected gasoline fuel injection system. Individual injectors feed from a continuous supply of high-pressure fuel available at a fuel rail. The ECU controls common rail supply pressure, as well as the start of injection, injection rate shape and quantity of fuel injected.

Fig. 3-9



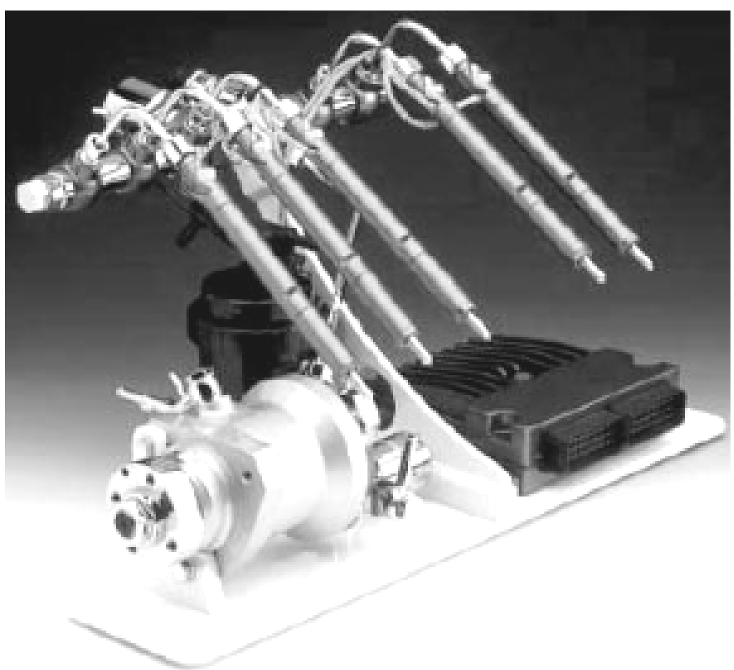
Common Rail Injection System contributes to the Advanced Clean Diesel System

All internal combustion engines need two key ingredients in order to operate: air and fuel. The precise delivery of these ingredients is what makes clean and powerful combustion possible. Just as turbochargers help deliver great amounts of air in order to help diesels operate cleanly, efficiently and powerfully; **high fuel pressure produces a fine mist of fuel that burns better and cleaner in the combustion chamber. For each combustion cycle, the common rail allows up to five injections per cycle. The benefits are; lower fuel consumption, better engine performance and less noise as compared to older diesel systems.**

The way in which an injector delivers fuel into the cylinders determines the torque, fuel consumption, emissions and noise level of diesel engines. Two factors are important: the fuel pressure as it enters the cylinder and the shape and number of the injections.

A common-rail injection system separates the functions of generating pressure and injecting fuel by first storing the fuel under high pressure in a central accumulator rail then delivering it to the individual electronically-controlled injection valves (injectors) on demand. This ensures that incredibly high injection pressures (over 25,000 PSI in some systems) remain available at all times, even at low engine speeds.

Fig. 3-10



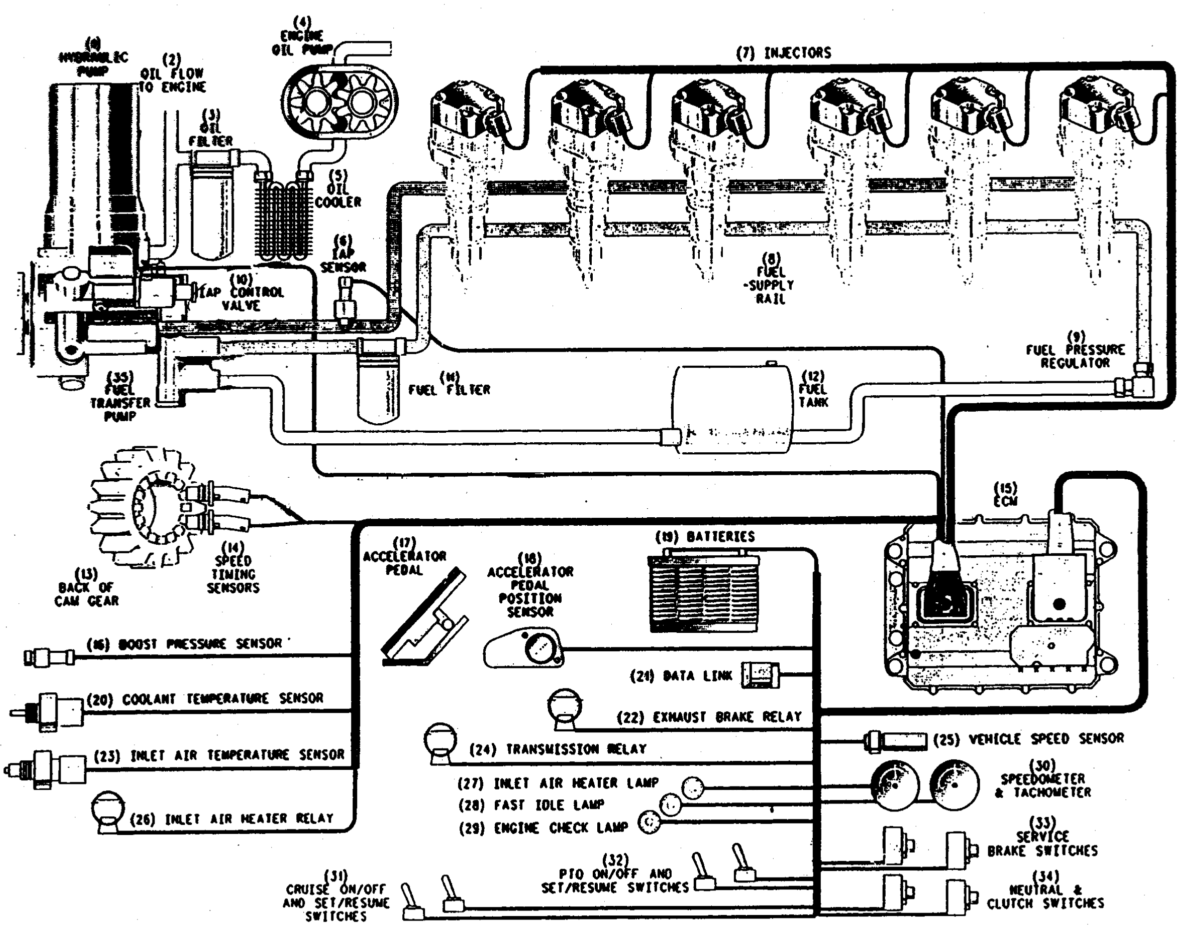
Hydraulic Electronic Unit Injection

A solution to the shortcomings of the electronic unit injector system is **the Hydraulic Electronic Unit Injector (HEUI) system developed by Caterpillar. In this system, a constant supply of high pressure engine oil feeds each injector and allows the injector to produce the required high injection pressure.**

A solenoid located in each injector controls the hydraulic system, allowing for a wide range of control over the injection event without the high-pressure distribution system used by common rail injection systems.

Using high-pressure lube oil from the engine to power down the piston of the injector barrel, the HEUI system lowers noise and allows for a much broader range of control over fuel delivery/timing.

Fig. 3-11



Exhaust Gas Recirculation (EGR) Systems

Exhaust gas recirculation (EGR) (routing some of the exhaust gas to the intake manifold) is widely used in internal combustion/spark-ignited engines to control NOx emissions. Unlike most spark-ignited applications, **use of EGR in a diesel engine requires electronic control of the EGR and EGR cooling to limit the associated increase in Particulate Matter (PM).** Since EGR displaces part of the intake air, it can increase the overall fuel-to-air equivalence ratio to a point that can lead to large increases in PM emissions. Hot EGR furthers this problem by increasing the temperature of the intake air. The increased temperature decreases air density and further reduces the volume of intake air entering the engine.

Exhaust Gas Recirculation (EGR) is an effective strategy in controlling NO_x emissions from diesel engines. The EGR reduces NO_x by lowering the oxygen concentration in the combustion chamber, as well as through heat absorption. Some of the existing configurations include high and low-pressure loop EGR, as well as hybrid systems. **Cooled EGR additions to the systems - in which an EGR cooler using jacket water cools recirculated exhaust gas have been put into operation to further reduce NO_x emissions.**

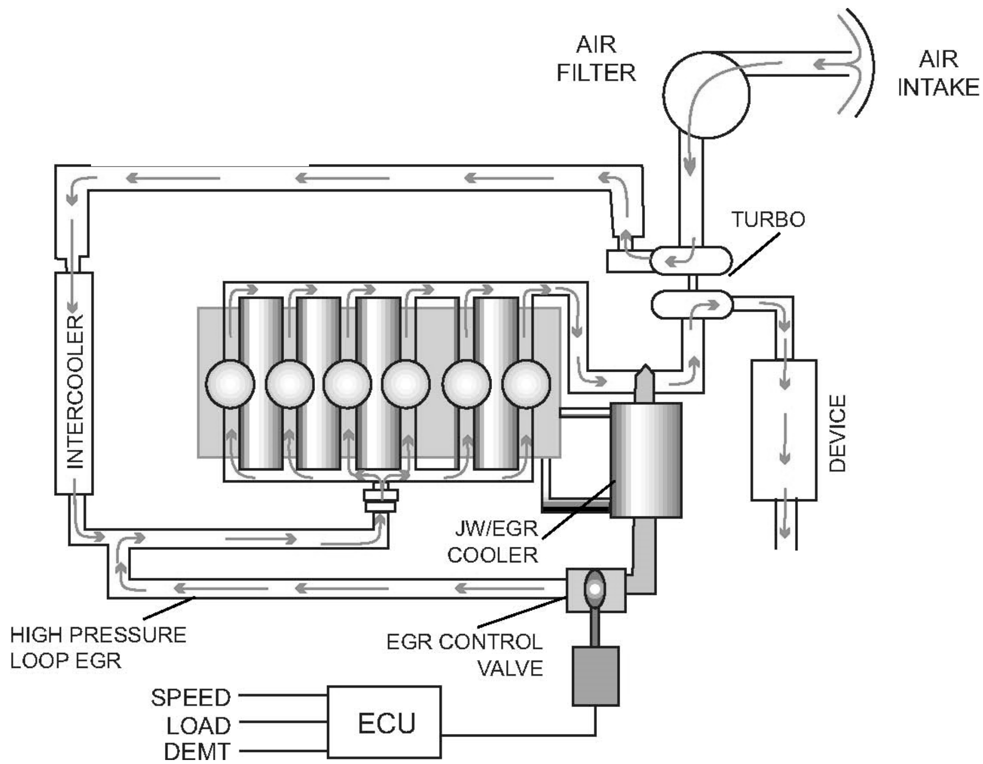
Cooled EGR systems typically use an engine coolant heat exchanger to cool the recirculated exhaust gases before mixing with the intake air. EGR cooling can significantly reduce the increase in intake air temperature associated with EGR. Though EGR cooling greatly extends the operational range over which EGR can be used, electronic control of the EGR is necessary to prevent large PM increases under hard acceleration.

Fig. 3-12

HPL EGR

A portion of the exhaust flow returns to the engine cylinders through an electronically controlled EGR valve after cooling. The common term for this approach is high-pressure loop (HPL) EGR. High-pressure loop EGR used with heavy-duty diesel engines has enabled NO_x reduction to the US Federal Test Procedure (FTP) level of 2.0 grams/brake horse power hour (g/bhp-hr.)

Fig. 3-13

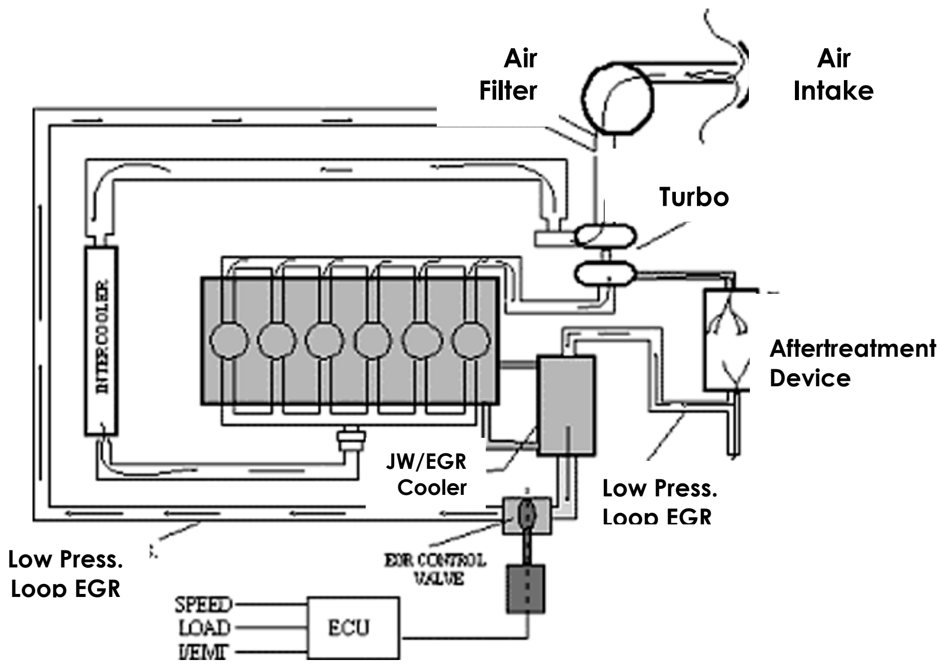


In HPL EGR design, turbocharger matching usually compensates for a loss of turbocharger effectiveness that happens when a portion of the exhaust is intercepted and the energy re-routed away from the turbine wheel. To increase the pressure drop between the exhaust and intake manifolds, some application use a venturi to help EGR flow into the engine inlet duct. These designs normally increase the kinetic energy of EGR, allowing more of it to flow with lower pumping losses.

LPL EGR

Another EGR design in heavy-duty diesel engines is **the low-pressure loop system (LPL EGR). These are often used in combination with particulate filter-based after treatment systems. The LPL EGR system may add several benefits.**

Fig. 3-14



To help the flow, EGR re-enters the engine just upstream of the turbocharger compressor. The pressure difference between points downstream of the trap and upstream of the turbocharger is generally adequate for the EGR flow rates needed to reduce NO_x to the mandated level required for heavy-duty diesel engines.

Advantages of the LPL EGR system include:

- **Lower fuel consumption and better turbocharger performance**
- **Preserving engine durability by using a particulate filter to admit filtered exhaust through the turbocharger compressor to the inlet of the engine.**
- **Higher heat absorbing capacity for flow rates similar to those of the HPL EGR, since exhaust gas downstream of the particulate filter is cooler than that from upstream of the turbocharger (as in the HPL case).**
- **The opportunity to reduce EGR cooler size, and provide a more compact unit, because of the higher heat-absorbing capacity. In addition, the EGR cooler would have less heat rejected in the engine water jacket minimizing the cooling load the radiator has to handle.**
- **Prevention of exhaust system condensation and erosion of the EGR cooler, EGR valve, and EGR piping as well as the turbocharger compressor wheel due to the reduction of the amount of EGR cooling.**
- **Better EGR and fresh charge air mixing, resulting from introducing the mixture upstream of the turbocharger compressor.**

The LPL EGR system has not been favored over the HPL system for the following reasons:

- Even though LPL EGR enters from a point downstream from the particulate filter, it is still not entirely free from carbonaceous material, since the filter trapping effectiveness is less than 100 percent. Carbon material remaining in the recirculated exhaust stream can impact the compressor wheel and may cause an erosion of the wheel.

- In cases using air-to-air intercoolers, the narrow cooler passages would trap carbon and other unfiltered matter flowing through the compressor. Build up over time would reduce air flow to the engine leading to deterioration in, engine performance, fuel economy as well as emissions quality.

- Unburned oil vapors and unburned fuel adsorbed on the surface of carbon particles that accumulate in the inlet system, emit carbon monoxide (CO) gas when exposed to higher temperatures. CO would displace fresh, cooled air from the engine, severely impacting combustion efficiency.

- The plumbing for the LPL EGR arrangement is often awkward and cumbersome.

Hybrid EGR

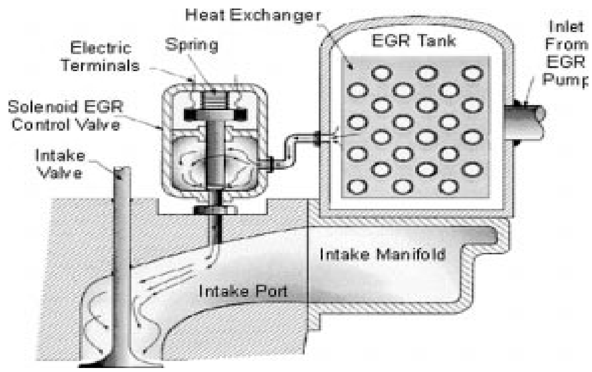
Some manufacturers will use a hybrid EGR system combining features of both HPL and LPL. EGR comes from a point upstream from the turbine (pre-turbine), as in a HPL configuration. It enters at a point pre-compressor, as in a LPL configuration**.**

While this system presents some of the same unfavorable features of the LPL EGR system, it provides an adequate pressure differential between the exhaust and intake manifolds, allowing EGR rates for substantial NOx reduction without the need for a pump or excessive exhaust backpressure to drive EGR into the engine.

Fast-acting EGR systems

The fast-acting EGR system minimize the EGR volume, making it easier for the engine to accelerate without interference from residual EGR by using a reservoir with a shell-and-tube EGR cooler to store cooled EGR. The EGR valve is situated very close to the intake port; reducing the volume of exhaust that an engine must consume during acceleration. EGR enters the intake port at a position close to the intake valve.

Fig. 3-15



If EGR comes from a pre-turbine point, then the fast-acting EGR system fits the description of HPL EGR. On the other hand, if it comes from downstream of the trap, it would be a LPL EGR system (which might require an EGR pump to elevate its pressure above that of the intake manifold).

Many diesel EGR systems use a high pressure loop configuration. This design taps exhaust gases from between the exhaust manifold and the turbocharger; sends them through the EGR cooler; them meters them into the intake air using an EGR valve. The challenge with the system is how to make EGR gases flow when the intake pressure is being boosted by the turbocharger. This is typically addressed using an intake throttle valve and or a variable geometry turbocharger (VGT). The throttle valve can be used to lower the pressure at the intake manifold, and the VGT can be used to increase exhaust pressure. The PCM will actuate these controls to optimize EGR flow for all engine operating conditions.

Manifold Vacuum Regulator Valve (Single Valve or Dual Switching Valve)
The Manifold Vacuum Regulator Valve for diesel engines regulates the intake manifold vacuum to achieve preferred rates of flow. Increasing the vacuum in the manifold will create suction on the EGR system when opened. This causes a higher flow rate that can reduce emissions, particularly the formation of NOx.

Fig. 3-16

Dual Valves switch intake sources between hot and cold to aid in the performance of Particulate Trap systems.

Fig. 3-17

Exhaust Air Control Valve (Post Combustion)
The exhaust air control valve is typically associated with the EGR function in the diesel air control system, where it may be used to vary and/or restrict the flow of exhaust gases and air. It may be used with particular effectiveness in the air control systems of large displacement or heavy-duty diesel engines, especially those typically found in large heavy-duty trucks, tractor-trailers, and other commercial vehicles and equipment.

Perform and enhance the EGR function for large displacement diesel engines.

Helps improve catalyst heating.

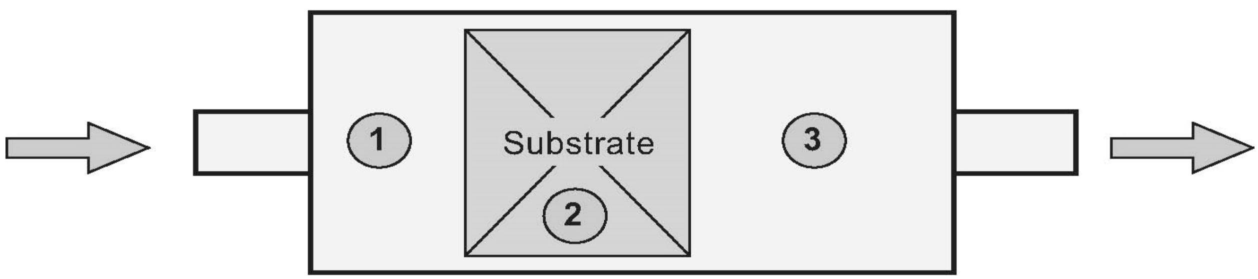
Fig. 3-18

Catalysts and Traps

Diesel Oxidation Catalysts

Diesel oxidation catalysts (DOC's) consist of a monolith honeycomb substrate coated with platinum group metal catalysts packaged in a stainless steel container. Using a honeycomb structure with many parallel channels allows for a high catalytic contact area for the exhaust gases. DOC's oxidize CO, HC, and the SOF (unburned fuel) fraction of particulate matter. Conversion of diesel particulate matter is an important role of the modern DOC. These catalysts also oxidize sulfur dioxide present in diesel exhaust following the combustion of fuels containing sulfur.

Fig. 3-19



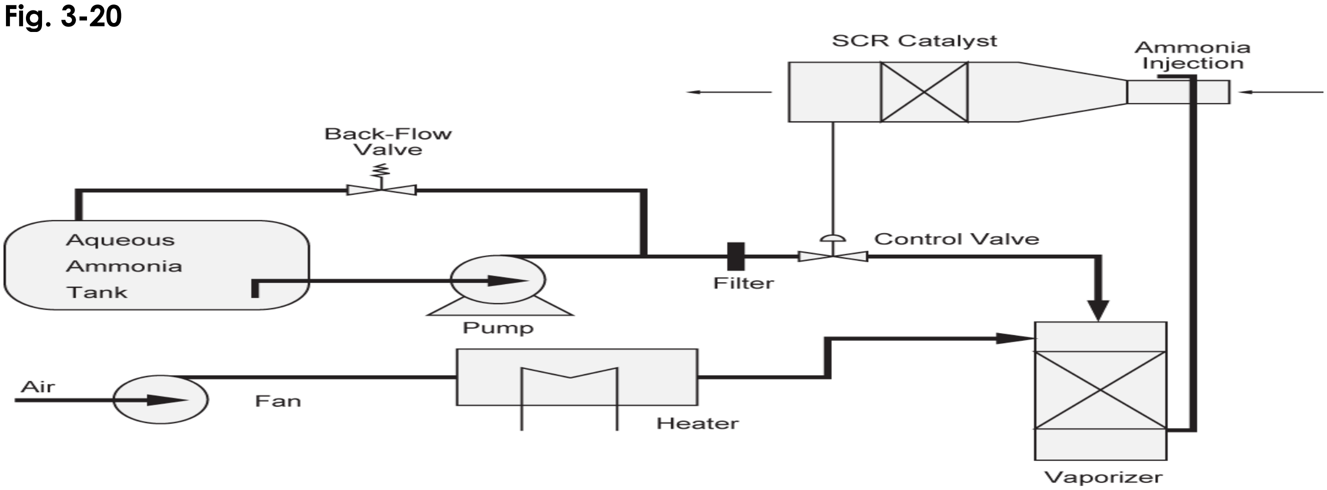
1. Flow distribution & acoustic (muffler)
2. Catalytic conversion
3. Acoustic (muffler)

Selective Catalytic Reduction

Industrial processes and stationary diesel engine applications have employed Selective Catalytic Reduction (SCR) of NO_x using ammonia or urea for many years. In the SCR process, NO_x reacts with the ammonia injected into the flue gas stream before the catalyst. Different SCR catalyst systems (based on platinum, vanadium oxide or zeolites) have different operating-temperature windows. Each particular SCR process requires the careful selection of a. specific type of SCR catalyst. Several commercial marine applications also use these systems.

SCR is still the only catalyst technology capable of reducing diesel NO_x emissions to the levels required by future emission standards. Numerous development programs have adapted the SCR technology to mobile diesel engines.

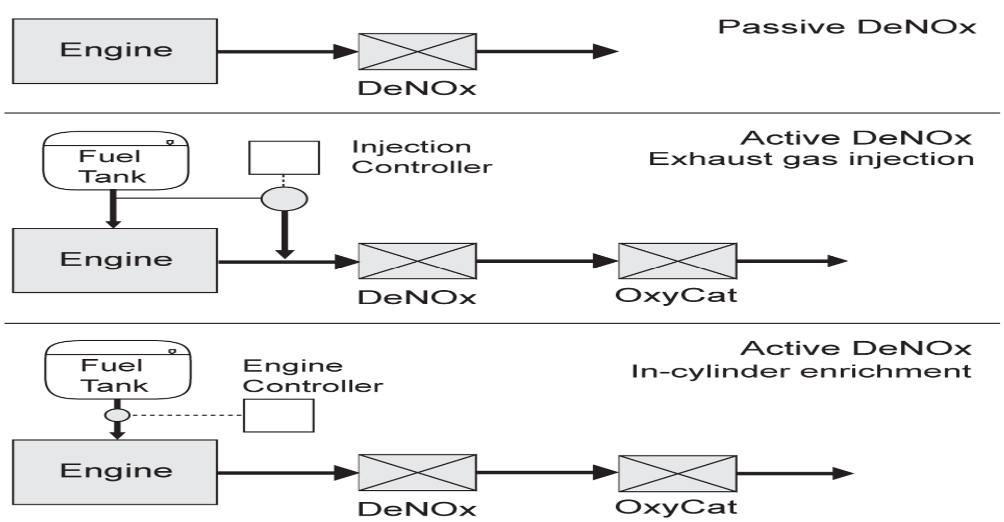
Fig. 3-20



Lean NO_x Catalyst

Two groups of catalyst systems reduce of NO_x with hydrocarbons: a copper substituted zeolite ZSM-5 catalyst (active at high temperatures) and a platinum/alumina catalyst (exhibiting low temperature activity). Both catalysts have narrow operating temperature windows. This results in only a limited NO_x reduction efficiency and contributes to other problems. In an attempt to provide small de-NO_x functionality in diesel oxidation catalysts, some commercial applications have adopted lean NO_x catalysts.

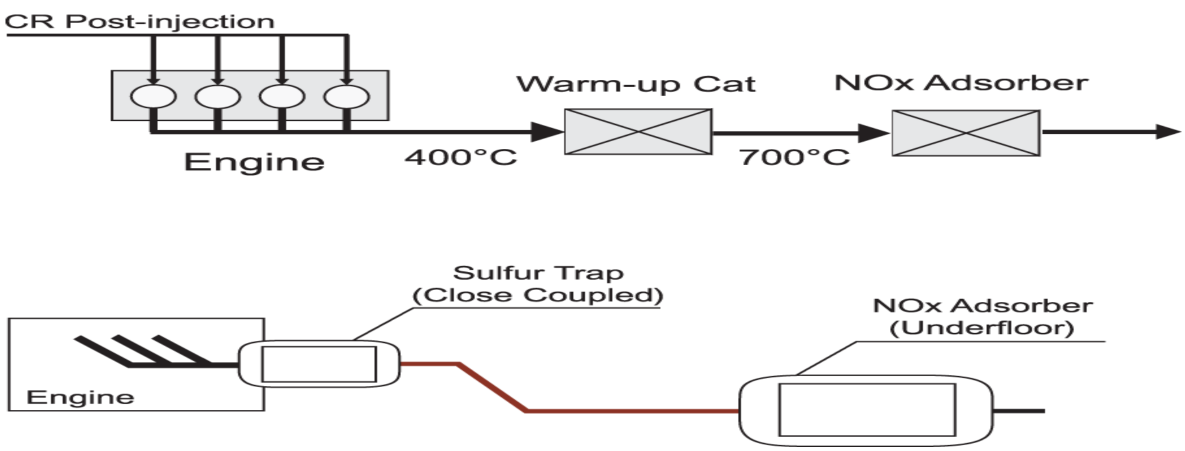
Fig. 3-21



NO_x Adsorbers

NOx adsorbers (traps) are the newest control technology under development for diesel and partial lean burn gasoline engines. **The adsorbers incorporated into the catalyst washcoat chemically bind oxides of nitrogen during lean engine operation. After the adsorber becomes saturated, the system regenerates and catalytically reduces released NO_x during a period of rich engine operation**.

Fig. 3-22



Deactivation of Diesel Catalyst

Poisoning and thermal degradation caused by either lubrication-oil additives or sulfur may cause a deactivation of the diesel catalysts. Phosphorus is the most common oil-derived catalyst poison. Sulfur is uniformly distributed over the catalyst length and washcoat depth, while phosphorus is selectively adsorbed at the catalyst inlet and in a thin, outer washcoat layer.

Diesel Particulate Filters

Diesel particulate filters are used to physically particulate matter and soot from diesel exhaust.

Diesel Filter Regeneration

A dynamic balance between the soot captured and oxidized in the filter will characterize the regeneration of diesel filters. Soot oxidation rates depend on the filter temperature, soot load in the filter and a number of other factors. Continuously regenerating filters operate at a balanced temperature, which can be determined through a laboratory measurement. To accomplish filter regeneration on diesel engines in real operation, exhaust gas temperature must be increased or the soot ignition temperature must be lowered using a catalyst.

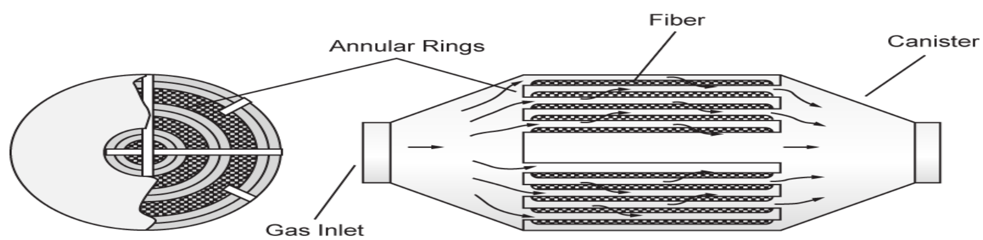
Wall-Flow Monoliths

Wall-flow monoliths are the most popular diesel filter design. They stem from flow-through catalyst supports where alternatively plugged channel ends force the gas flow through porous walls that act as filters. Wall-flow monoliths are made from such specialized ceramic materials as cordierite and silicon carbide. A number of mechanical and thermal properties describe and set apart different monoliths. Filters of different sizes have been developed and are available as standard products.

Ceramic Fibers and Cartridges

Cartridges for filtering diesel particulates can be made from high-temperature ceramic fibers. Fiber filters capture particulates through depth filtration mechanisms. A number of cartridge designs have been developed. Some of them incorporate electric heaters for regeneration.

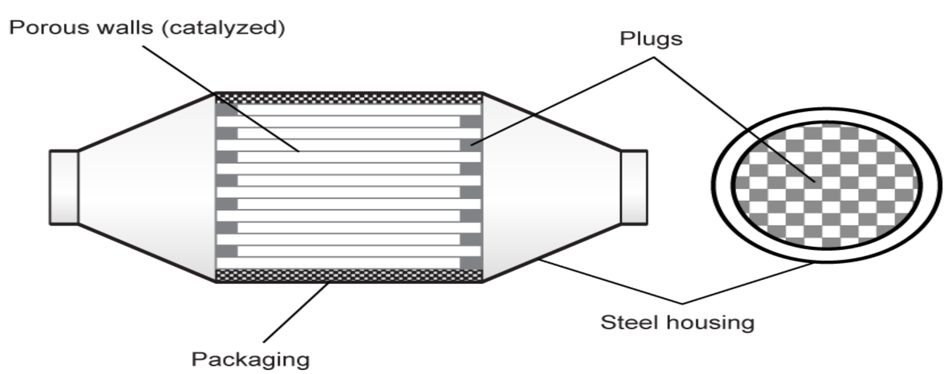
Fig. 3-23



Catalyzed Diesel Filters

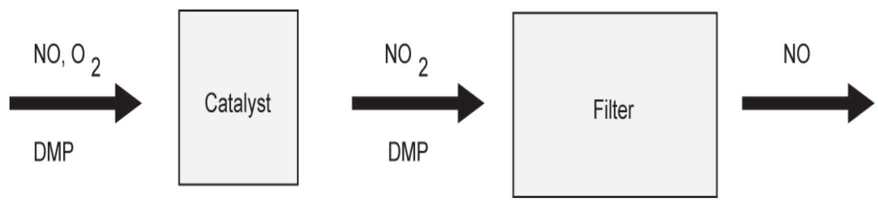
Most catalyzed diesel filters use monolithic wall-flow substrates coated with a catalyst. The catalyst lowers the soot combustion temperature, allowing the filter to self-regenerate during periods of high exhaust gas temperature. A number of diesel filter catalysts have been developed, including both noble and base metal formulations. Catalyzed ceramic traps exhibit very good DPM filtration efficiencies, but exhibit relatively high exhaust gas pressure drop.

Fig. 3-24



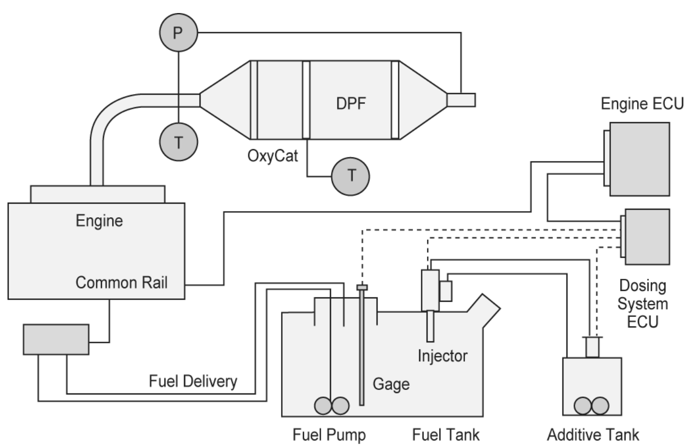
CRT Filter
The CRT is a trade name for a two-stage, catalytic, passive filter configuration. The CRT system uses a ceramic wall-flow filter to trap particulates. Nitrogen dioxide produced in an oxidation catalyst placed upstream of the filter continuously oxidizes the trapped particulate matter. The CRT requires ultra-low-sulfur fuel and a certain minimum NO_x/PM ratio for proper operation.

Fig. 3-25



Filters with Fuel Additives
Fuel additives (also called fuel soluble catalysts) can lower the soot combustion temperature and facilitate filter regeneration in passive diesel filter systems. The most common additives include iron, cerium and platinum.

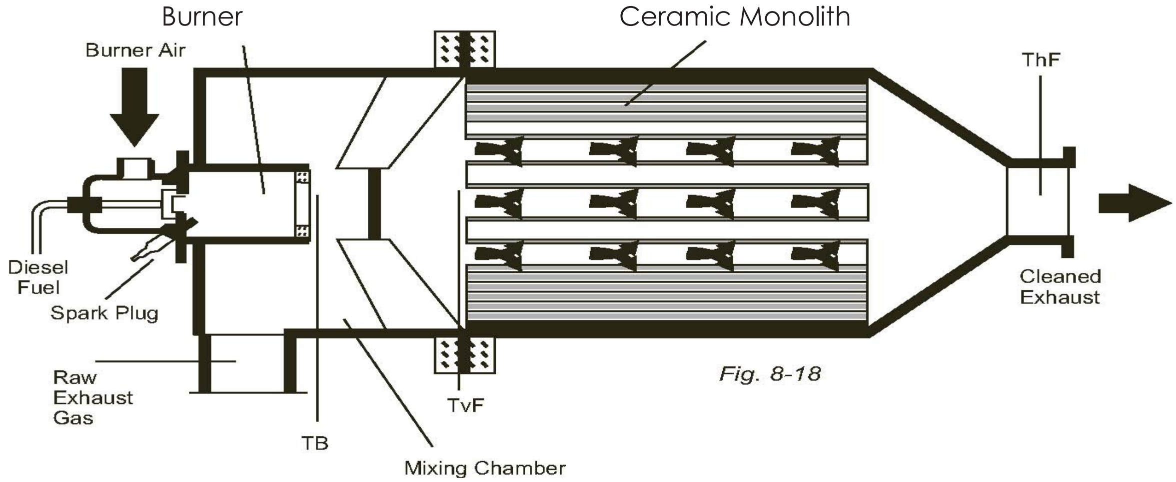
Fig. 3-26



Electrically Regenerated Filters
The electric regeneration of diesel filters can follow on-board and various off-board configurations. On-board regeneration by means of an electric heater connected to the vehicle power source puts a significant additional load on the vehicle electrical system. Partial-flow layouts or regeneration with hot air are more energy efficient. Some filter systems require an external power source or are removed from the vehicle for off-board regeneration known as stationary regeneration.

Filters with Fuel Burners
Diesel fuel burners can increase the exhaust gas temperature upstream of a particulate filter in order to facilitate its regeneration. Fuel burner filters fall into two categories: single-point and full-flow systems. The full-flow systems can regenerate during regular vehicle operation but require complex control strategies to ensure a thermally balanced regeneration

Fig. 3-27



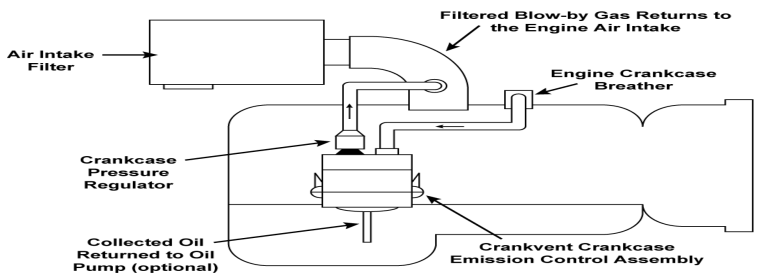
Regeneration is the removal or cleaning of PM that has been collected by the particulate filter. The key is maintaining sufficient exhaust temperatures so that the system can continually clean the Pm from the filter. This is known as Passive regeneration. Under conditions where there is not enough heat in the exhaust Active regeneration is used. This is done by raising the exhaust temperatures with the injection of minute amounts of fuel upstream of the DOC. Both passive and active regeneration can happen while the vehicle is operating.

Notes:

Crankcase Ventilation Systems

Crankcase blow-by is produced when combustion gases, under high-pressure, become contaminated with oil mist when blown past the piston rings into the crankcase. As engine manufacturers reduce exhaust emissions, **crankcase blow-by vented to the atmosphere has become a larger contributor to total emissions.** To further reduce the total emissions of engines, it is becoming necessary to route these gases into the air intake system.

Fig. 3-28



In a closed system, this contaminated blow-by is ingested by the engine intake system. While the closed crankcase breather system offers the highest reduction in measurable emissions, the impact of unfiltered crankcase blow-by on engine components and performance must be considered. Many manufacturers use a CCV filtering system to prevent damage that can be caused by heavy blow-by or excessive oil mist coating the intake system.

Other systems more closely resemble the PCV or positive crank case vent of a spark ignited engine. These positive flow type systems use a blower or air compressor system to force air thru the crankcase and into the air induction system.

Routine maintenance required for the Crankcase Ventilation Filter System is filter replacement. Typical service intervals are recommended in the manufactures service information. Some variations in service life occur depending on load profile, engine wear condition, flow and aerosol mass concentration of crankcase emissions, and soot concentration.

Fig. 3-29

STUDY QUESTIONS

POWER, FUEL ECONOMY & LOW EMISSIONS

1. How much of a power improvement is the norm on a diesel engine with a turbo?

A. 40 to 50%

B. 90 to 100%

C. 30 to 40 %

D. No power improvement-it quiets the engine

2. The Electronic Direct Injection System is ____________________.

A. the least fuel efficient of all systems

B. a belt-driven unit

C. programmable for optimal performance over the entire engine's speed range

D. not programmable and has difficulties providing fuel at low speed

3. One way to get more power out of a diesel engine is to increase the volume of air and fuel by:

A. removing the air cleaner

B. adding a larger diameter exhaust system

C. adding a forced induction device such as a turbocharger

D. adding a particulate trap system

4. A wastegate on a turbo ______________________________________.

A. causes a turbo to overboost

B. causes the engine to be sluggish

C. allows a smaller turbo to be used to reduce lag

D. allows fuel to be wasted to lighten the load

5. <u>Yes/No</u> - **An Exhaust Gas Recirculation (EGR) on a diesel engine requires both electronic control of the EGR and EGR cooling to limit the increase in Particulate Matter (PM)?**

6. **The Engine/Electronic Control Module (ECM) controls ___________________________, as well as working with the Electronic Driver Unit (EDU) to provide a strong precise signal for each cylinder's combustion**

   A. fuel rail pressure for precise fuel delivery

   B. cylinder pressure

   C. fuel tank pressure for the evaporative system

   D. transmission pressure

7. **A common-rail injection system separates the functions of generating pressure and injecting fuel by _________________________.**

   A. storing the fuel under extremely high pressure in central accumulator rail

   B. using a constant supply of high pressure engine lube oil

   C. delivering the fuel to the individual electronically-controlled injectors on demand

   D. Both A and C

8. **The exhaust air control valve is effectively used in air control systems of large displacement or heavy duty diesel engines to:**

   A. to restrict air flow re-entering the engine

   B. to perform and enhance the EGR function and help improve catalyst heating

   C. replace the EGR, since it doesn't work well on a diesel

   D. None of the above

9. **The most popular diesel filter design is ________________.**

A. NOx Adsorbers	B. Diesel Filter Regeneration
C. Lean NOx Catalyst	D. Wall-Flow Monoliths

10. Closed crankcase breather systems offer the highest reduction in blow-by emissions by________________.

A. allowing the engine to vent to atmosphere

B. routing the blow-by gases to the particulate trap system

C. routing these gases into the air intake system

11. <u>Yes/No</u> - The Fast-Acting EGR system greatly minimizes the EGR volume, making it easier for the engine to accelerate without interference from residual EGR by storing the cooled EGR.

12. <u>True/False</u> - Crankcase Ventilation Systems are designed to re-route blow-by gasses into the air intake system.

13. True/False - Selective Catalyst Reduction is the only catalyst technology capable of reducing NOx to the levels required by the future EPA emissions standards?

14. The advantages of using a Low Pressure Loop (LPL) EGR, rather than HLP EGR are ______________________________.

A. the designs will normally increase the kinetic energy of EGR; allowing more it to flow with lower pumping losses.

B. better turbocharger performance and lower fuel consumption

C. the introduction of additional recirculated heated air into the engine

D. All of the above

Common-Sense Approach To Diesel Emissions

Diesel Emissions

Diesel Engine Operation

Power, Fuel Economy & Low Emissions

Electronic Control of Diesel Emissions

Understanding and Using Scan Data

Diesel Emissions & Smoke Diagnostics

Troubleshooting Charts

Study Questions Answer Key

Glossary

FOUR

Electronic Control of Diesel Engines

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Today's Diesel Systems

Today's diesel systems **all use one or more on-board computers (including the ECM, ABS or PCM) to control the engine; transmission; and/or antilock brake system.**

These computers work with an assortment of sensors. They include:

Speed Sensors
Engine Speed Sensors
Engine Coolant Temperature Sensor and many more…

These sensors generate electronic or digital signals that provide input to the Engine/Electronic Control Module (ECM). The ECM controls the operation of the vehicle.

To properly repair the vehicle, the technician should have access to all the information shared between the vehicle's ECM and sensors. On a modern vehicle**, knowledge of input and output values, component location and wiring schematics** are essential to performing successful repairs.

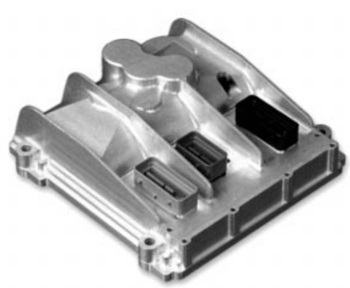
Electronically connected components that permit an information processing cycle have three distinct stages:

Data Input (sense)
Data processing (decide)
Outputs (act)

Engine/Electronic Control Module System Functions

Regulate Reference Voltage (V-REF)
Input Conditioning, Amplification, and ADC (Analog to Digital Converter)
Processing
Manage Output Drivers

Fig. 4-1



The Basics First

Over the years on-board computers have increased in their ability to control and monitor vehicle systems. This includes adaptive strategies; the substitution of values for failed sensors and the ability to relearn information.

Even with the advancement of on-board computers, some areas remain unchanged. The computer still needs a good power supply and ground, the mechanical parts of the engine must be in good operating condition, the fuel and its delivery system must both be sound and the proper amount of air must enter the induction system.

Before rushing to the computer or a computer component, **check the basic systems first.** Listed are a few areas that could cause you to extend your diagnostic time or misdiagnosis the problem:

Battery and Charging systems
Grounds Vehicle & Computer
Wiring harness/connectors
Engine operating temperature
Exhaust restrictions
Fuel pressure and volume
Leaking Fuel Pressure Regulator
Engine compression
Crankcase pressure
Sticking/dirty injectors
Glow Plugs/Relay (if equipped)
Boost pressure
Waste Gate operation
Restricted intake
Carbon deposits
Engine oil (check level, correct grade/viscosity, check for contaminants)

Values seen on scan tool data stream may be different from voltages at a sensor or actual state of an output device, always verify with DVOM.

Notes:

Heavy Duty Diesel Performance Diagnostics

Perform all tests with engine at operating temperature

Fig. 4-2

Test	Pass	Fail	Action
Check Engine Oil Level: Check for contaminants • Fuel, coolant Check for correct • Grade • Viscosity			Oil contaminated: • change oil and filter Wrong grade: • change oil and filter Wrong Viscosity: • change oil and filter
Fuel: Take sample from tank Inspect for contamination			If fuel contaminated: drain and clean system Replace all filters, change oil
Fuel Pressure: *Measure:* • Pressure at proper test point • Pressure at high idle • Pressure at Fuel Filter • Pressure at full load • Pressure at rated speed *Tool:* Use proper tool: a gauge that reads At least 160psi			Check manufacturers' specs for vehicle being tested. Pressure low: • Inspect fuel lines • Replace filter • Clean strainer • Retest
Transfer Pump Restriction: *Measure:* • Vacuum at fuel pump inlet • Vacuum at high idle *Tool:* Vacuum gauge			Check manufacturers' specs for vehicle being tested. Restriction high: • Check for blockage between pump and fuel tank Restriction within specs: • Check for sticking regulator valve or debris in system
Intake Restriction: Check filter minder (if equipped) *Measure:* • At high idle no loads *Spec:* • 12.5" H20 Max. *Tool:* Manometer or Magnehelic gauge			Check manufacturers' specs for Vehicle being tested. If yellow band is latched @ 25" H20 • Replace filter Repair or replace all necessary components of air intake system to allow proper flow.
Exhaust Restriction: • Visually inspect exhaust system for damage *Measure:* • After turbo outlet (3"to 6") • Full load and rated speed *Tool:* Manometer or Magnehelic gauge			Check manufacturers' specs for Vehicle being tested. Damaged exhaust system: • Repair/Replace necessary components Fails to meet specs on test: • Replace necessary components • Retest

Fig. 4-3

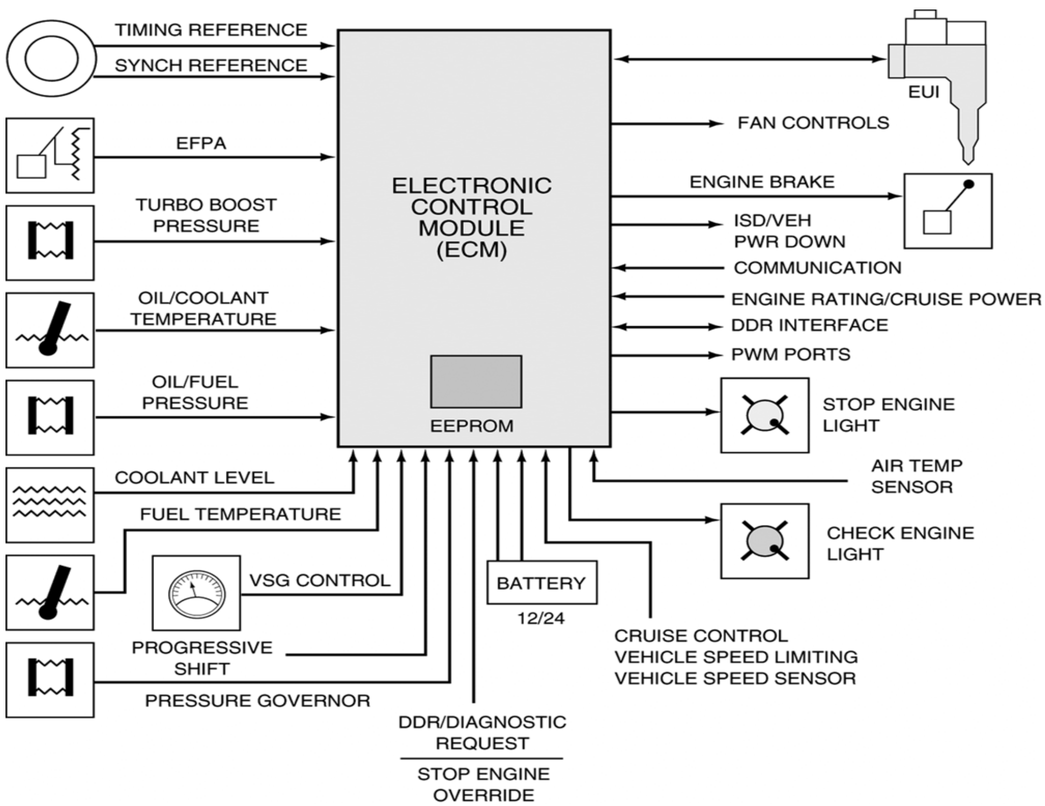
Test	Pass	Fail	Action
Boost Pressure: *Measure:* Pressure at full load & rated speed *Tool:* • Dash tachometer and 0-30 PSI gauge • EST tool			Check manufacturers' specs for Vehicle being tested. *Check for the following:* • Restricted intake or exhaust • Low fuel pressure • Low injection control pressure • Control system faults • Defective injectors • Defective turbocharger • Base engine failure Repair/Replace as necessary, retest
Crankcase Pressure: Check manufacturers' specs for Vehicle being tested. *Measure:* • Pressure at proper test point • High idle no load • *Tool* • Magnehelic gauge			Check manufacturers' specs for Vehicle being tested. *Check for the following:* • Worn piston • Broken piston rings • Stuck piston rings • Worn or scored cylinder sleeves • Blown Air compressor head gasket • Worn Air compressor rings • Turbocharger seal failure • Excessive guide wear or leaking guide seals • Leaking intake manifold/valve cover gasket Repair/Replace as necessary, retest
Wastegate Actuator Test: Apply regulated air to actuator Inspect for: • Leakage • Actuator for movement *Tool:* PSI gauge			Check manufacturers' specs for Vehicle being tested. *Check for the following:* • Sticky flapper valve • Ruptured actuator diaphragm • Leaky canister • Leaky hose to actuator
Valve Clearance: Check clearance with feeler gauge: • Engine Off • Hot or Cold			Check manufacturers' specs for Vehicle being tested. Adjust to manufacturers specs Cannot adjust to specs, check the following: • Worn valve train components • Valve seat or face wear
Injector Control Pressure Monitor pressure and engine rpm with EST *Check readings at:* • Low idle • High idle • Full load			Check manufacturers' specs for Vehicle being tested. If readings are out of specs, check for the following: • Defective regulator valve • Defective high pressure pump • Injection control pressure system leakage ECM commanding a reduction in fuel pressure Check for: • Low boost pressure • Incorrect APS reading • Incorrect feedback signal

Data Input

Data comes from the following monitoring sensors:

Command Sensors
Thermistor
Switches
Signal Generator
Potentiometer
Variable Capacitors

Fig. 4-4



Sensors include anything that signals input data to the ECM. The signals used can be either analog or digital.

Supplied 5-Volt reference (usually)

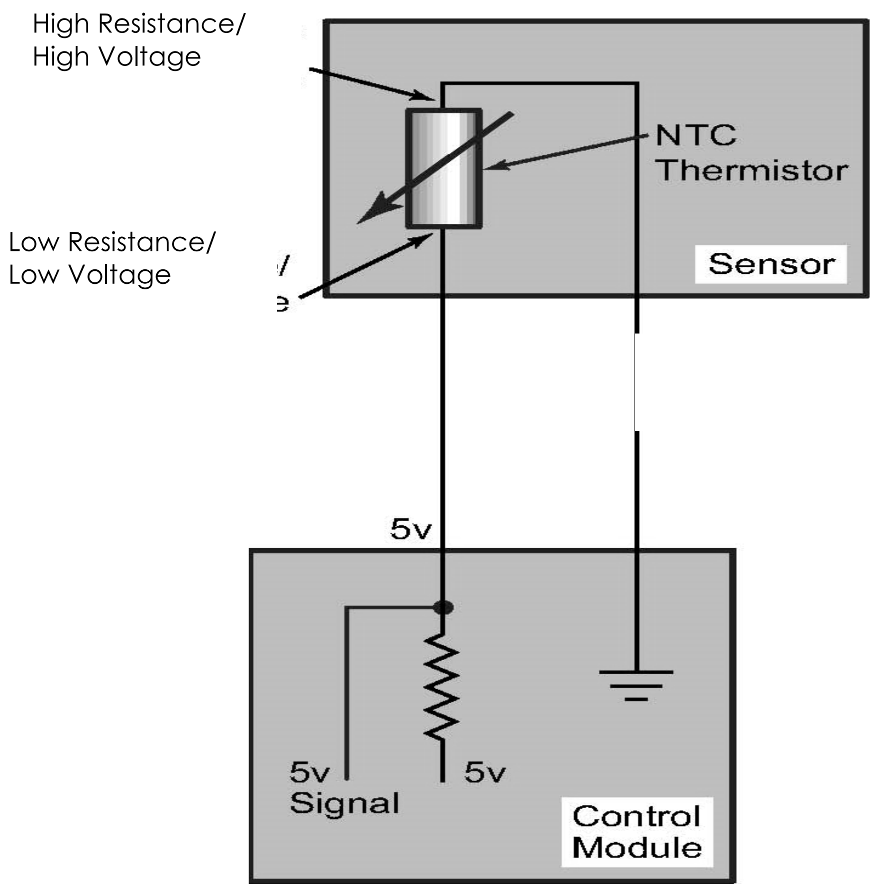
ECM compares the return signals

Types of Sensors

Thermistors
Function like a variable resistor; as the temperature changes, the thermistor's resistance changes.

> **NTC (Negative Temperature Co-efficient) resistance decreases as temperature increases**
>
> **PTC (Positive Temperature Co-efficient) resistance increases as temperature increases**

Fig. 4-5



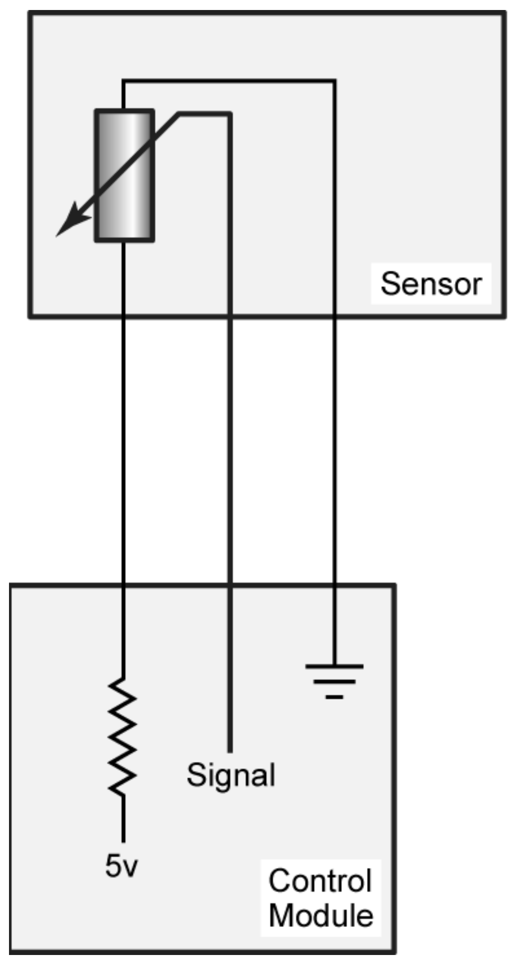
Variable Capacitance Sensors

Three-Wire Sensor
Supplied with Reference Voltage
Designed to Measure Pressure
Signal from Sensor Analog

Used to measure/monitor:

Oil Pressure/MAP/BARO

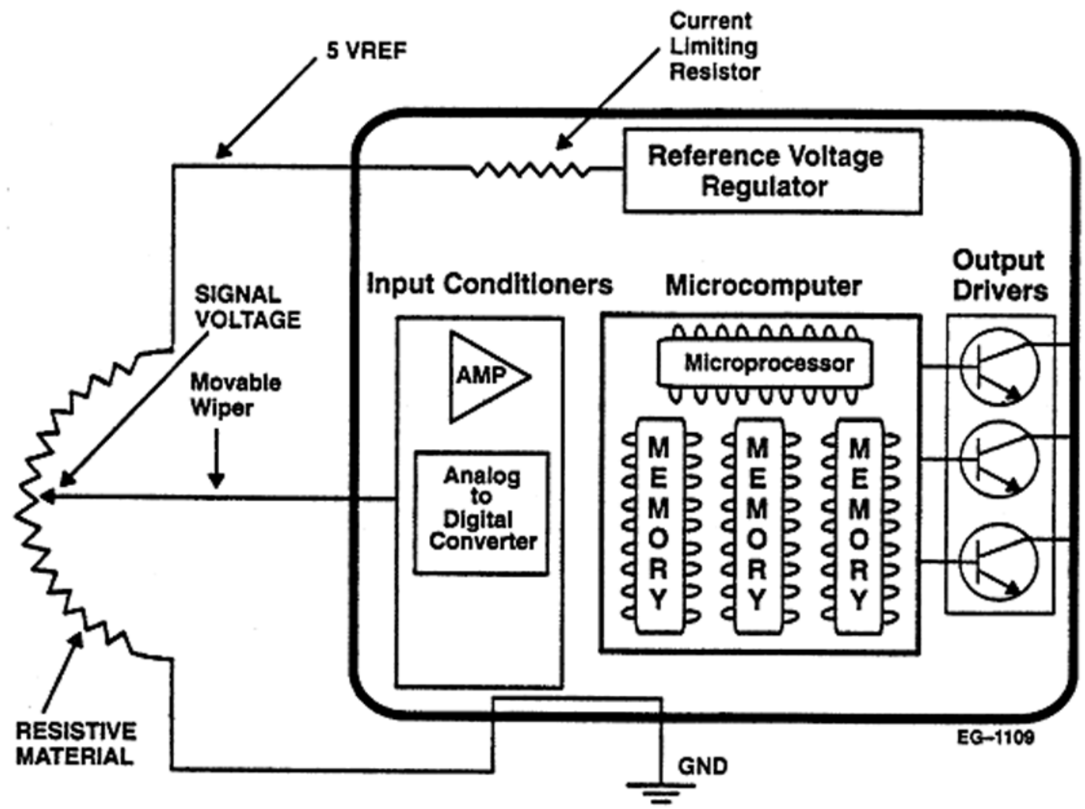
Fig. 4-6



Potentiometers

Three-wire sensor
Analog signal proportional to the position of a mechanical device

Fig. 4-7 - Potentiometer (Variable Resistance Voltage Divider)



NOTES:

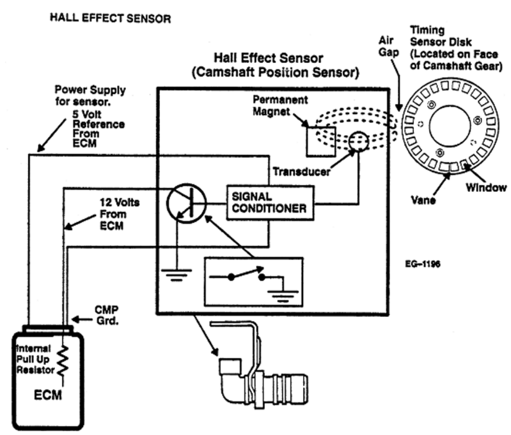
Signal Generating Sensors

Three-wire sensor
Digital signal
Supplied reference voltage

Used for:

CPS camshaft sensor
TRS timing reference sensor
EPS engine position sensors

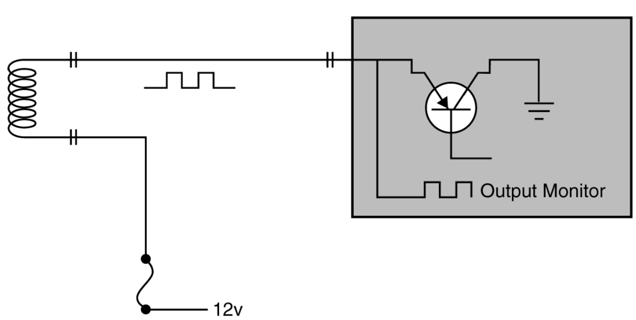
Fig. 4-8



Outputs/Actuators

Fan Controls
Fuel Injectors
Retarder Solenoids
Idle Speed

Fig. 4-9



Data Processing

Central Processing Unit (CPU) – Electronic Control Module (ECM) in the Heavy-Duty (HD) industry):

Executes program instructions

Random-Access Memory (RAM):

Electronically retained data, can be manipulated by (CPU/ECM) primary or main storage (note pad)
At start-up, RAM is electronically loaded with vehicle-management operating instructions and all necessary running data retained in other data categories
Data storage is temporary called (volatile) memory
Most HD ECMs use only volatile memory when an EEPROM is used
Non-volatile memory is used when no EEPROM is used in system

Read-Only Memory (ROM):

Input and magnetically retained data, transferred to (RAM) for processing
Permanent information, designed not to be overwritten
Susceptible to damage from magnetic fields
Master program for system management is loaded into ROM
ROM contains all the protocols (rules and regulations) to master engine management

Programmable Read-Only Memory (PROM):

Contains tire size, fuel delivery tables, gear ratios for differential and transmission applicable to a specific chassis application
Reprogramming is done by replacing the chip

Electronically Erasable PROM (EEPROM):

Contains customer data, programmable options and proprietary data that can be altered and modified using a variety of tools

Two Types of Reprogramming

Customer Data

Tire rolling radius
Governor type
Cruise control limits/transmission ratio
Road speed limit/torque rise profile
Shutdown sensors/peak brake power
Idle speed/idle shutdown duration

Proprietary

Fuel mapping
System monitoring
Command inputs

STUDY QUESTIONS

ELECTRONIC CONTROL OF DIESEL ENGINES

1. To properly repair a modern diesel vehicle, the technician should have knowledge of

A. input and output values

B. component location and wiring schematics

C. a way of accessing information shared between the vehicle's ECM and sensors

D. All of the above

2. Variable Capacitance sensors are used to measure:

A. Oil Pressure

B. Manifold Absolute Pressure

C. Barometric Pressure

D. All of the above

3. Signal generating sensors provide information such as timing, camshaft position?

A. Yes

B. No, they provide information about temperature

4. The output of a potentiometer is ___________________ .

A. a digital signal that is proportional to motion of a mechanical device

B. a frequency that is proportional to motion of a mechanical device

C. a signal responding to the pressure created by a sensor

D. an analog voltage signal that is proportional to the position of a mechanical device

5. **<u>True or False</u> - One of the four basic functions for an ECM on a diesel is managing output drivers?**

   A. True

   B. False

6. **The master program for system management which contains permanent information that is designed not to be overwritten is called _________.**

   A. Random Access Memory (RAM)

   B. Programmable Read-Only Memory (PROM)

   C. Read-Only Memory (ROM)

   D. Electronically Erasable PROM

Common-Sense Approach To Diesel Emissions

Diesel Emissions

Diesel Engine Operation

Power, Fuel Economy & Low Emissions

Electronic Control of Diesel Emissions

Understanding & Using Scan Data

Diesel Emissions & Smoke Diagnostics

Troubleshooting Charts

Study Questions Answer Key

Glossary

FIVE

Understanding & Using Scan Data

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Diagnostic Connectors

The most-common diagnostic connectors for Heavy-Duty vehicles are the Deutsch 6- and 9-pin connectors. The two connectors allow you to access the on-board systems. Using the Heavy Duty Standard application software, you can access the following:

Data Stream
Codes (Active and Inactive)
Clear Codes
Trip Information

Most new vehicles power up through the diagnostic connector.

Fig. 5-1 & Fig. 5-2

6 – PIN Deutsch Connector

A PIN	J1708 +
B PIN	J1708 -
C PIN	Battery +
D PIN	Not Used
E PIN	Battery -
F PIN	Re-program

9 – PIN Deutsch Connector

A Pin	Battery +
B Pin	Battery -
C PIN	CAN +
D PIN	CAN -
E PIN	CAN Shield
F PIN	J1708 +
G PIN	J1708 -
H PIN	OEM Specific
I PIN	OEM Specific

The diagnostic connector is usually located under the dash on the left side of vehicle. However, the diagnostic connector can also be found in any of the locations below:

In the center of the dash
Hidden behind panels
Behind or under drivers seat
On the right side of the vehicle
Engine compartment

You should always refer to the vehicle's shop manual for the proper location and proper diagnostic connector to be used.

Heavy Duty Vehicle Data Lists

Each manufacturer has a set data list based on the electronic system being used. The early systems were very limited in data. However, the industry has advanced to 32-bit processors and an almost endless data stream.

Using the generic Heavy Duty Standard reader, a limited data stream of information can be retrieved.

Observing certain sensors information and grouping them together will help to accurately diagnosis.

Related Data Parameter Categories

Data parameters group into fields relating to engine and vehicle operating systems. Some vehicles will have more fields than others, as well as more data for each field. During troubleshooting, it is sometimes necessary to evaluate several parameters from two or more categories together for an accurate diagnosis. The lists below show the different categories:

General/Shared Parameters
Several different vehicle systems need this information in order to operate. **Most vehicles include engine/vehicle speed, indications of general ECM output commands, overall system condition and engine load.**

Fuel Delivery Parameters
This information covers fuel delivery and the output commands from the ECM to fuel control devices.

Accelerator Pedal Position (Throttle Position) and Idle Control Parameters
This information covers the position of the accelerator (throttle) and the operating condition of various idle speed control devices. This information could indicate ECM command to idle and accelerator (throttle) control devices.

Engine Coolant, Oil, Transmission Oil, Fuel Temperature Parameters
This information covers the engine and fuel temperature, as well as the temperature or condition of the coolant, engine oil and transmission fluid.

Air Pressure, Manifold Pressure, and Turbocharger Parameters
This information covers ambient air pressure and high or low pressure inside the intake manifold. **The ECM uses these input parameters for the engine protection system, injection timing, fueling control, and to monitor conditions that could derate the engine.**

Airflow and Air Temperature Parameters
This information covers the primary input parameters that the ECM uses for the engine protection system, the timing and fueling control, and the airflow rate.

Electrical Parameters
This information covers the condition of the vehicle electrical system.

Heating, Ventilating and Air Conditioning Parameters
This information covers ECM commands to and signals from various actuators and sensors in the HVAC system. On some vehicles, ECM signals to and from the engine cooling fan control the cooling fan's operation.

Trip Information

Trip List
The TRIP LIST shows accumulated vehicle system information.
Not all applications provide all of this information

The Heavy-Duty Standard application will display the following vehicle system information:

Trip Miles	Vehicle Hours	Idle Fuel
Engine Hours	Engine Revs	Total Miles
Idle Hours	Instant Fuel MPG	
Total Fuel Gallons	Average Fuel MPG	
Trip Fuel Gallons	PTO Hours	

Most vehicle manufacturers give more information and choices. See the examples below:

Caterpillar Application:
Trip menu selections:

Current totals	Reset Driver
Fleet trip	Data MPH Histogram
Reset Fleet Trip Data	RPM Histogram
Driver Trip Data	Trip Data

The ECM maintains current totals for the following parameters:

Engine Hours	PTO Hours
Miles	Idle Fuel
Maximum Fuel	Idle Hours
Fuel Average	Load Factor (calculated)
PTO Fuel	Fleet Trip Data

The ECM maintains Fleet Trip Data for the following:

Time
Driving Time
Fuel
Overall Fuel Economy
Driving Fuel Economy
Idle time
Idle fuel
Percent idle time
PTO Time
PTO Fuel
Driver Trip Data
Percent PTO Time
Average Load Factor
Average Vehicle Speed
Average Driving Speed
Maximum Vehicle Speed
Maximum Engine Speed
Start Time
End Time
Start Odometer
End Odometer

Interactive Diagnostics/Bi-directional Control/Functional Testing

Functional testing is a very important feature of any scan tool. Being able to turn on actuators to perform functionality testing is critical. A properly-run wiggle test on a Navistar/International vehicle can help find a needle in an electrical haystack. A voltage-drop test during an output-state test can find the phantom bad ground. Allison World Transmission uses Action Requests to enable/disable the clutch test.

Consider the following example. The vehicle that is being working on has failed an emissions test. Starting the vehicle, excessive white smoke and a rough-running engine is noticed. A bad injector is suspected as causing a misfire condition. On most vehicles, a cylinder cutout or injector test is performed using the scan tool and bi-directional control.

Caterpillar Interactive Diagnostics:
Vehicle Speed Test
Cylinder Cutout
Injector Solenoid
MT/AT Transmission Test
Retarder/Exhaust Test
Tachometer Circuit Test
Multi-function Output #1 Test
Multi-function Output #3 Test
Cooling Fan/Multi-function Output #4 Test
Injection Actuation Pressure Driver Test
Inlet Air Heater Test
Rack BTM Sweep Test
Shut-Off Solenoid Test
Timing BTM Sweep Test
Multi-Function Output #2 Test

Navistar/International:
Diagnostic Tests

<u>1. Engine Off Test</u>
Standard Test
Injector Test
Wiggle Test
Output State Test

<u>2. Engine Running Test</u>
Standard Test
Injector Test
Wiggle Test

Data Categories

Understanding Diagnostic Codes
The Society of the Automotive Engineers (SAE) and The Maintenance Council (TMC) of the American Trucking Association developed a standard data interchange format/set-up referred to as J1587.

This standard data interchange format/set-up identifies the messages that are sent from one electrical device to another on a vehicle serial data link. It defines a standard data list, controller names and numbers, parameter names and numbers, and diagnostic fault code formats and numbers.

MESSAGE IDENTIFIERS (MIDS)
MIDS identify the controller that is sending the message (engine, transmission, brakes)

MIDS are the microprocessors used in heavy-duty vehicle applications. These microprocessors transmit messages on the Serial Data Link (SDL) and control the engine, transmission and brakes. J1922 MIDs (69-86) are used on a dedicated communication link for interactive control between electronic engine, transmission, ABS/Traction Control and retarder systems. J1587 MIDs (128-186) are used by the microprocessors to communicate messages and data on a common link.

Fig. 5-19

MID 128	PID 065	SID 247	FMI 04
Engine	Service Brake Switch Status	Brake Pedal Switch #2	Voltage Below Normal or Shorted Low

MID	DESCRIPTION	MID	DESCRIPTION
128	ENGINE # 1	176	TRANSMISSION, ADDITIONAL
129	TURBOCHARGER	177	PARTICULATE TRAP SYSTEM
130	TRANSMISSION	178	VEHICLE SENSORS TO DATA CONVERTER
131	POWER TAKEOFF	179	DATA LOGGING COMPUTER
132	AXLE, POWER UNIT	180	OFF-BOARD DIAGNOSTICS # 2
133	AXLE, TRAILER #1	181	COMMUNICATION UNITSATELLITE
134	AXLE, TRAILER # 2	182	OFFBOARD PROGRAMMING STATION
135	AXLE, TRAILER # 3	183	ENGINE # 3
136	BRAKES, POWER UNIT	184	ENGINE # 4
137	BRAKES, TRAILER # 1	185	ENGINE # 5
138	BRAKES, TRAILER # 2	186	ENGINE # 6
139	BRAKES, TRAILER # 3	187	VEHICLE CONTROL HEAD UNIT
140	INSTRUMENT CLUSTER	188	VEHICLE LOGIC CONTROL HEAD
141	TRIP RECORDER	189	VEHICLE HEAD SIGNS
142	VEHICLE MGMT SYSTEM	190	REFRIGERANT MGMT SYSTEM
143	FUEL SYSTEM	191	VEHICLE LOCATION UNIT-DIFFERENTIAL CORRECTION
144	CRUISE CONTROL	192	FRONT DOOR STATUS UNIT
145	ROAD SPEED INDICATOR	193	MIDDLE DOOR STATUS UNIT
146	CAB CLIMATE CONTROL	194	REAR DOOR STATUS UNIT
147	CARGO REFRIGERATION/HEATING TRAILER # 1	195	ANNUNCIATOR UNIT
148	CARGO REFRIGERATION/HEATING TRAILER # 2	196	FARE COLLECTION UNIT
149	CARGO REFRIGERATION/HEATING TRAILER # 3	197	PASSENGER COUNTER UNIT
150	SUSPENSION, POWER UNIT	198	SCHEDULE ADHERENCE UNIT
151	SUSPENSION, TRAILER # 1	199	ROUTE ADHERENCE UNIT
152	SUSPENSION, TRAILER # 2	200	ENVIRONMENT MONITOR UNIT
153	SUSPENSION, TRAILER # 3	201	VEHICLE STATUS POINTS MONITOR
154	DIAGNOSTIC SYSTEMS, POWER UNIT	202	HIGH SPEED COMMUNICATIONS UNIT
155	DIAGNOSTIC SYSTEMS,TRAILER # 1	203	MOBILE DATA TERMINAL UNIT
156	DIAGNOSTIC SYSTEMS,TRAILER # 2	204	VEHICLE PROXIMITY, RIGHT SIDE
157	DIAGNOSTIC SYSTEMS, TRAILER # 3	205	VEHICLE PROXIMITY, LEFT SIDE
158	ELECTRICAL CHARGING SYSTEM	206	BASE UNIT (RADIO GATEWAY TO FIXED END)
159	PROXIMITY DETECTOR, FRONT	207	BRIDGE FROM J1708 DRIVETRAIN LINK
160	PROXIMITY DETECTOR, REAR	208	MAINTENANCE PRINTER
161	AERODYNAMIC CONTROL UNIT	209	VEHICLE TURNTABLE
162	VEHICLE NAVIGATION UNIT	210	BUS CHASSIS IDENTIFICATION UNIT
163	VEHICLE SECURITY	211	SMART CARD TERMINAL
164	MULTIPLEX	212	MOBILE DATA TERMINAL
165	COMMUNICATION UNIT GROUND	213	VEHICLE CONTROL HEAD TOUCH SCREEN
166	TIRES, POWER UNIT	214	SILENT ALARM UNIT
167	TIRES, TRAILER # 1	215	SURVEILLANCE MICROPHONE
168	TIRES, TRAILER # 2	216	LIGHTING CONTROL ADMINISTOR UNIT
169	TIRES, TRAILER # 3	217	TRACTOR/TRAILER BRIDGE,TRACTOR MOUNTED
170	ELECTRICAL	218	TRACTOR/TRAILER BRIDGE,TRACTOR MOUNTED
171	DRIVER INFORMATION CENTER	219	COLLISION AVOIDANCE RADAR
172	OFF-BOARD DIAGNOSTIC # 1	220	TACHOGRAPH
173	ENGINE RETARDER		
174	CRANKING/STARTING SYSTEM		
175	ENGINE # 2		

SUBSYSTEM IDENTIFIERS (SIDS)

SIDS identify the part of the controller that has a fault (engine timing actuator, brake relay). The SID is identified by a number and a description in a standardized list.

SID	DESCRIPTION	SID	DESCRIPTION
001	INJECTOR CYLINDER # 1	**044**	AUTOSHIFT LOW GEAR ACTUATOR
002	INJECTOR CYLINDER # 2	**045**	AUTOSHIFT NEUTRAL ACTUATOR
003	INJECTOR CYLINDER # 3	**046**	AUTOSHIFT COMMON LOW SIDE (RETURN)
004	INJECTOR CYLINDER # 4	**047**	INJECTOR CYLINDER # 17
005	INJECTOR CYLINDER # 5	**048**	INJECTOR CYLINDER # 18
006	INJECTOR CYLINDER # 6	**049**	INJECTOR CYLINDER # 19
007	INJECTOR CYLINDER # 7	**050**	INJECTOR CYLINDER # 20
008	INJECTOR CYLINDER # 8	**051**	AUXILIARY OUTPUT DEVICE DRIVER # 3
009	INJECTOR CYLINDER # 9	**052**	AUXILIARY OUTPUT DEVICE DRIVER # 4
010	INJECTOR CYLINDER # 10	**053**	AUXILIARY OUTPUT DEVICE DRIVER # 5
011	INJECTOR CYLINDER # 11	**054**	AUXILIARY OUTPUT DEVICE DRIVER # 6
012	INJECTOR CYLINDER # 12	**055**	AUXILIARY OUTPUT DEVICE DRIVER # 7
013	INJECTOR CYLINDER # 12	**056**	AUXILIARY OUTPUT DEVICE DRIVER # 8
014	INJECTOR CYLINDER # 14	**057**	AUXILIARY PWM DRIVER # 1
015	INJECTOR CYLINDER # 15	**058**	AUXILIARY PWM DRIVER # 2
016	INJECTOR CYLINDER # 16	**059**	AUXILIARY PWM DRIVER # 3
017	FUEL SHUTOFF VALVE	**060**	AUXILIARY PWM DRIVER # 4
018	FUEL CONTROL VALVE	**061**	VARIABLE SWIRL SYSTEM VALVE
019	THROTTLE BYPASS VALVE	**062**	PRESTROKE SENSOR
020	TIMING ACTUATOR	**063**	PRESTROKE ACTUATOR
021	ENGINE POSITION SENSOR	**064**	ENGINE SPEED SENSOR # 2
022	TIMING SENSOR	**065**	HEATED OXYGEN SENSOR
023	RACK ACTUATOR	**066**	IGNITION CONTROL MODE SIGNAL
024	RACK POSITION SENSOR	**067**	IGNITION CONTROL TIMING SIGNAL
025	EXTERNAL ENGINE PROTECTION INPUT	**068**	SECONDARY TURBO INLET PRESSURE
026	AUXILIARY OUTPUT DEVICE DRIVER # 1	**069**	AFTER COOLER-OIL COOLANT TEMP
027	VARIABLE GEOMETRY TURBOCHARGER ACTUATOR # 1	**070**	INLET AIR HEATER DRIVER # 1
028	VARIABLE GEOMETRY TURBOCHARGER ACTUATOR # 2	**071**	INLET AIR HEATER DRIVER # 2
029	EXTERNAL FUEL COMMAND INPUT	**072**	INJECTOR CYLINDER # 21
030	EXTERNAL SPEED COMMAND INPUT	**073**	INJECTOR CYLINDER # 22
031	TACHOMETER OUTPUT	**074**	INJECTOR CYLINDER # 23
032	WASTEGATE OUTPUT DEVICE DRIVER	**075**	INJECTOR CYLINDER # 24
033	FAN CLUTCH OUTPUT DEVICE DRIVER	**076**	KNOCK SENSOR
034	EXHAUST BACK PRESSURE SENSOR	**077**	GAS METERING VALVE
035	EXHAUST BACK PRESSURE	**151**	SYSTEM DIAGNOSTIC CODE # 1
036	GLOW PLUG LAMP	**152**	SYSTEM DIAGNOSTIC CODE # 2
037	ELECTRONIC DRIVE UNIT POWER RELAY	**153**	SYSTEM DIAGNOSTIC CODE # 3
038	GLOW PLUG RELAY	**154**	SYSTEM DIAGNOSTIC CODE # 4
039	ENGINE STARTER MOTOR RELAY	**155**	SYSTEM DIAGNOSTIC CODE # 5
040	AUXILIARY OUTPUT DEVICE DRIVER # 2	**228**	HIGH SIDE REFRIGERANT PRESSURE SWITCH
041	ECM 8 VOLTS DC SUPPLY	**229**	KICKDOWN SWITCH
042	INJECTION CONTROL PRESSURE	**230**	IDLE VALIDATION SWITCH
043	AUTOSHIFT HIGH GEAR ACTUATOR	**231**	SAE J1939 DATA LINK

SID	DESCRIPTION	SID	DESCRIPTION
232	5 VOLTS DC SUPPLY	244	CRUISE CONTROL ENABLE SWITCH
233	CONTROLLER # 2	245	CLUTCH PEDAL SWITCH # 1
234	PARKING BRAKE ON ACTUATOR	246	BRAKE PEDAL SWITCH # 1
235	PARKING BRAKE OFF ACTUATOR	247	BRAKE PEDAL SWITCH # 2
236	POWER CONECT DEVICE	248	PROPRIETARY DATA LINK
237	START ENABLE DEVICE	249	J-1922 DATA LINK
238	DIAGNOSTIC LAMP - RED	250	J-1708 (J-1587) DATA LINK
239	DIAGNOSTIC LAMP – AMBER	251	POWER SUPPLY
240	PROGRAM MEMORY	252	CALIBRATION MODULE
242	CRUISE CONTROL RESUME SWITCH	253	CALIBRATION MEMORY
243	CRUISE CONTROL SET SWITCH	254	CONTROLLER

PARAMETER IDENTIFIERS (PIDS)

PIDS identify the data in the message (coolant temperature, engine RPM). The PID is identified by a number and a description in a standardized list.

PID	DESCRIPTION	PID	DESCRIPTION
040	ENGINE RETARDER SWITCHES STATUS	066	VEHICLE ENABLING COMPONENT STATUS
041	CRUISE CONTROL SWITCHES	067	SHIFT REQUEST SWITCH STATUS
042	PRESSURE SWITCH STATUS	068	TORQUE LIMITING FACTOR
043	IGNITION SWITCH STATUS	069	TWO SPEED AXLE SWITCH STATUS
044	ATTENTION/WARNING INDICATOR LAMP STATUS	070	PARKING BRAKE SWITCH
045	INLET AIR HEATER STATUS	071	IDLE SHUTDOWN TIMER STATUS
046	VEHICLE WET TANK PRESSURE	072	BLOWER BYPASS VALVE POSITION
047	RETARDER STATUS	073	AUXILIARY WATER PUMP STATUS
048	EXTENDED RANGE BAROMETRIC PRESSURE	074	MAXIMUM ROAD SPEED LIMIT
049	ABS CONTROL STATUS	075	STEERING AXLE TEMPERATURE
050	A/C COMPRESSOR CLUTCH STATUS/COMMAND	076	AXLE LIFT AIR PRESSURE
051	THROTTLE POSITION	077	FORWARD REAR DRIVE AXLE TEMPERATURE
052	ENGINE INTERCOOLER TEMPERATURE	078	REAR REAR DRIVE AXLE TEMP
053	TRANSMISSION SYNCHRONIZER CLUTCH VALVE	079	ROAD SURFACE TEMPERATURE
054	TRANSMISSION SYNCHRONIZER BRAKE VALVE	080	WASHER FLUID LEVEL
055	SHIFT FINGER POSITIONAL STATUS	081	PARTICULATE TRAP INLET PRESSURE
056	TRANSMISSION RANGE SWITCH STATUS	082	AIR START PRESSURE
057	TRANSMISSION ACTUATOR STATUS # 2	083	ROAD SPEED LIMIT STATUS
058	SHIFT FINGER ACTUATOR STATUS	084	ROAD SPEED
059	SHIFT FINGER GEAR POSITION	085	CRUISE CONTROL STATUS
060	SHIFT FINGER RAIL POSITION	086	CRUISE CONTROL SET SPEED
061	PARKING BRAKE ACTUATOR STATUS	087	CRUISE CONTROL HIGH SET LIMIT SPEED
062	RETARDER INHIBIT STATUS	088	CRUISE CONTROL LOW SET LIMIT SPEED
063	TRANSMISSION ACTUATOR STATUS #1	089	POWER TAKEOFF STATUS
064	DIRECTION SWITCH STATUS	090	POWER TAKEOFF OIL TEMPERATURE
065	SERVICE BRAKE SWITCH STATUS	091	PERCENT ACCELERATOR PEDAL POSITION

PID	DESCRIPTION	PID	DESCRIPTION
092	PERCENT ENGINE LOAD	**150**	PTO ENGAGEMENT CONTROL STATUS
093	OUTPUT TORQUE	**151**	ATC CONTROL STATUS
094	FUEL DELIVERY PRESSURE	**152**	NUMBER OF ECU RESETS
095	FUEL FILTER DIFFERENTIAL PRESSURE	**153**	CRANKCASE PRESSURE
096	FUEL LEVEL	**193**	TRANSMITER SYSTEM DIAGNOSTIC TABLE
097	WATER IN FUEL INDICATOR	**194**	TRANSMITER SYSTEM DIAGNOSTIC CODE & OCCURANCE COUNT TABLE
098	ENGINE OIL LEVEL	**195**	DIAGNOSTIC DATA REQUEST/CLEAR RESPONCE
099	ENGINE OIL FILTER DIFFERENTIAL PRESSURE	**196**	DIAGNOSTIC DATA/COUNT CLEAR RESPONSE
100	ENGINE OIL PRESSURE	**197**	CONNECTION MANAGEMENT
101	CRANKCASE PRESSURE	**198**	CONNECTION MODE DATA TRANSFER
102	BOOST PRESSURE	**199**	TRACTION CONTROL DISABLE STATE
103	TURBO SPEED	**229**	TOTAL FUEL USED (NATURAL GAS)
104	TURBO OIL PRESSURE	**230**	TOTAL IDLE FUEL USED (NATURAL GAS)
150	INTAKE MANIFOLD TEMPERATURE	**231**	TRIP FUEL (NATURAL GAS)
106	AIR INLET PRESSURE	**232**	DGPS DIFFERENTIAL CORRECTION
107	AIR FILTER DIFFERENTIAL PRESSURE	**233**	UNIT NUMBER (POWER UNIT)
108	BAROMETRIC PRESSURE	**234**	SOFTWARE IDENTIFICATION
109	COOLANT PRESSURE	**235**	TOTAL IDLE HOURS
110	ENGINE COOLANT TEMPERATURE	**236**	TOTAL IDLE FUEL USED
111	COOLANT LEVEL	**237**	VEHICLE IDENTIFICATION NUMBER
112	COOLANT FILER DIFFERENTIAL PRESSURE	**238**	VELOCITY VECTOR
113	GOVERNOR DROOP	**239**	VEHICLE POSITION
114	NET BATERY AMPS	**240**	CHANGE REFERENCE NUMBER
115	ALTERNATOR AMPS	**241**	TIRE PRESSURE
116	BRAKE APPLICATION PRESSURE	**242**	TIRE TEMPERATURE
117	BRAKE PRIMARY PRESSURE	**243**	COMPONENT IDENTIFICATION
118	BRAKE SECONDARY PRESSURE	**244**	TRIP DISTANCE
119	HYDRAULIC RETARDER PRESSURE	**245**	TOTAL VEHICLE DISTANCE
120	HYDRAULIC RETARDER OIL TEMPERATURE	**246**	TOTAL VEHICLE HOURS
121	ENGINE RETARDER STATUS	**247**	TOTAL ENGINE HOURS
122	ENGINE RETARDER PERCENT	**248**	TOTAL PTO HOURS
123	CLUTCH DISENGAGE SWITCH	**249**	TOTAL ENGINE REVOLUTIONS
124	TRANSMISSION OIL LEVEL	**250**	TOTAL FUEL USED
125	TRANSMISSION OIL LEVEL HIGH/LOW	**251**	CLOCK
126	TRANSMISSION FILTER DIFFERENTIAL PRESSURE	**252**	DATE
127	TRANSMISSION OIL PRESSURE	**253**	ELAPSED TIME
128	COMPONENT-SPECIFIC REQUEST	**254**	DATA LINK ESCAPE
140	TIRE PSI CONTROL SYSTEM SOLENOID STATUS	**255**	EXTENSION
141	TRAILER TAG, OR PUSH CHANNEL TIRE PRESSURE		
143	STEER CHANNEL TIRE PRESSURE TARGET		
144	TRAILER TAG, OR PUSH CHANNEL TIRE PRESSURE		
145	DRIVE CHANNEL TIRE PRESSURE		
146	STEER CHANNEL TIRE PRESSURE		
147	AVERAGE FUEL ECONOMY (NATURAL GAS)		
148	INSTANTANEOUS FUEL ECONOMY (NATURAL GAS)		
149	FUEL MASS FLOW RATE (NATURAL GAS)		

FAILURE MODE IDENTIFIER (FMI)

FMIS identify how the system or part failed (shorted low, shorted high). The FMI is identified by a number and a description in a standardized list.

SAE FMI	DESCRIPTION
00	DATA VALID BUT ABOVE NORMAL RANGE
01	DATA VALID BUT BELOW NORMAL RANGE
02	DATA ERRATIC, INTERMITTENT, OR INCORRECT
03	VOLTAGE ABOVE NORMAL OR SHORTED HIGH
04	VOLTAGE BELOW NORMAL OR SHORTED LOW
05	CURRENT BELOW NORMAL OR OPEN CIRCUIT
06	CURRENT ABOVE NORMAL OR GROUNDED CIRCUIT
07	MECHANICAL SYSTEM NOT RESPONDING PROPERLY OR OUT OFADJUSTMENT
08	ABNORMAL FREQUENCY, PULSEWIDTH, PERIOD
09	ABNORMAL UPDATE RATE
10	ABNORMAL RATE OF CHANGE
11	FAILURE MODE NOT IDENTIFIABLE
12	BAD INTELLIGENT DEVICE OR COMPONENT
13	OUT OF CALIBRATION
14	SPECIAL INSTRUCTIONS

NOTES:

STUDY QUESTIONS

UNDERSTANDING & USING SCAN DATA

1. **Message Identifiers (MIDs) identify**

   A. Diagnostic trouble codes for engine control

   B. Memory chips for fuel control

   C. the controller sending the message

   D. Analog to digital converters

2. **The complete standard data interchange format that describes the messages that are sent from one electrical device to another on a vehicle serial data link is comprised/made up of**

   A. Message Identifiers (MIDs), & Subsystem Identifiers (SIDs)

   B. Parameter Identifiers (PIDs), & Failure Mode Identifiers (FMIs)

   C. Neither A or B

   D. Both A and B

3. **In the General/Shared parameter categories most vehicle manufacturers provide information about ___________________.**

   A. engine/vehicle speed

   B. engine load

   C. overall system condition

   D. All of the above

Common-Sense Approaches To Diesel Emissions

Diesel Emissions

Diesel Engine Operation

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Diesel Emissions & Smoke Diagnostics

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Preventative Maintenance & Emissions

Inspections and maintenance are vital to maintaining diesel engines in proper operating condition and also to minimizing major repairs caused by mechanical failures.

A relatively minor engine malfunction might well develop into a major mechanical repair, if not recognized and corrected at the onset of the problem. **The recognition of symptoms of developing malfunctions can be done by the use of ones senses; sight, hearing, smell, touch or feel (heat/vibration).**

Particular attention should be paid to the following signs of oncoming problems:

1. **Unusual noises**
2. **Vibrations**
3. **Abnormal temperatures**
4. **Abnormal pressures**
5. **Abnormal operating speeds**

Knowledge and familiarization with the specific temperatures, pressures, and operating speeds of the vehicles that is being serviced is required so that any deviation from the normal will be readily recognized.

When a gauge or other instrument gives an abnormal reading, the cause of the malfunction should be fully investigated. Normally the installation of a test tool, or a calibration test, will quickly indicate whether the abnormal reading is due to instrument error or whether further testing and diagnosing is required.

Due the safety factor commonly integrated in pumps and similar equipment, substantial loss of power can occur before any external indication is visible. Changes in the operating speeds, pressures or temperatures should be viewed with concern. Most variations from normal pressures, lubricating oil temperatures, and system pressures indicate either inefficient operation or poor condition.

Basic Maintenance Checks

Intake system

Inspection of intake system components; as well as inspection and/or replacement of filters, testing and maintaining piping, filter housing, gaskets, connection and seals; installation of appropriate gauges; appropriate servicing intervals; detection and correction of problems.

Exhaust system
Monitoring exhaust backpressure and emissions; evaluating the installation and/or damage of exhaust system components; monitoring the condition and performance of after-treatment devices.

Fuel Injection System
Diagnosing problems; scheduling checks of primary fuel pressure; examining filters; verifying air/fuel ratio; checking for fuel leaks, fuel temperature and air in fuel; using filtered vents on fuel tanks; adjustment and replacement of components.

Cooling System
Scheduling maintenance and cleaning of cooling systems; important service practices; verifying operating condition of gauges and alarm sensors; diagnosing and correcting problems.

Fuel Quality and Handling
Proper storage, transfer of fuels, filtration and cleanliness.

Diesel Smoke Diagnostics

Diesel smoke consists of particles too small to be seen individually, but collectively these particles become visible as black smoke in the exhaust stream of a diesel engine.

Black smoke is often an indicator that a diesel engine is in need of repair. The Heavy-Duty Diesel Vehicle Inspection/Maintenance (HDDV I/M) programs test to determine the amount of excessive smoke being emitted by the diesel vehicle. The targets of the HDDV I/M programs are the gross emitters. Depending on the nature of the program and the test method used, these tests take place under controlled conditions at an off-road facility or in some areas roadside checks are conducted. Each method follows standardized procedures. If an HDDV produces excessive emissions/smoke, the HDDV I/M program requires that the defect causing the emissions failure be repaired, penalties imposed or both.

Excessive smoke can result from:

Restricted or clogged air filters
Improper or malfunctioning injection timing
Clogged, worn, or mismatched injectors
A faulty fuel injection pump
A defective or malfunctioning puff limiter
Low air box pressure
Air manifold leaks
A malfunctioning turbocharger
A malfunctioning intercooler
A defective air/fuel controller
Poor fuel quality or a malfunctioning governor

Some of these defects result in too rich air/fuel mixtures, which, in turn results in excessive incomplete combustion.

Excessive smoke can also result from deliberate tampering. Common targets for tampering are:

Smoke puff limiters
Fuel pump calibration
Fuel injection timing
Excessive fuel flow rate

Tampering most often stems from an effort to obtain more power from the engine. Whether **excessive smoke is a result of tampering or poor maintenance practices, excessive smoke can result in higher operating costs, reduced fuel economy, higher maintenance costs and shorter engine life.**

Always check the service information available for the specific vehicle being diagnosed or repaired.

NOTES:

Blue Smoke

Root Cause and Condition:
Excessive blue smoke indicates problems such as low engine compression and/or worn piston rings, scored cylinder walls or leaking valve stem seals.

The blue smoke results from crankcase oil entering the combustion chamber, where it partially combusts before exiting through the exhaust stream.

Fig. 6-1

Normal Condition	Excessive Condition	Cause & Action
Blue Smoke: Can be observed during: Should not see	**Occurs During:** Acceleration Full Load	**Cause:** high concentrations of unburned or partially oxidized fuel or lubricating oil in the exhaust gas. This situation is typical of a diesel engine operating at low temperatures or suffering high oil consumption Action: Perform Performance test

Test	Pass	Fail	Action
Check Engine Oil Level: Check for contaminants • Fuel, coolant Check for correct • Grade • Viscosity			Oil contaminated: • change oil and filter Wrong grade: • change oil and filter Wrong Viscosity: • change oil and filter
Boost Pressure: *Measure:* Pressure at full load & rated speed *Tool:* • Dash tachometer and 0-30 PSI gauge • EST tool			Check manufacturers specs for Vehicle being tested. *Check for the following:* • Restricted intake or exhaust • Low fuel pressure • Low injection control pressure • Control system faults • Defective injectors • Defective turbocharger • Base engine failure Repair/Replace as necessary, retest
Wastegate Actuator Test: Apply regulated air to actuator Inspect for: • Leakage • Actuator for movement *Tool:* • PSI gauge			Check manufacturers specs for Vehicle being tested. *Check for the following:* • Sticky flapper valve • Ruptured actuator diaphragm • Leaky canister • Leaky hose to actuator

Refer to the smoke chart in section SEVEN

White Smoke

Root Cause & Condition:

The most-common reasons for white smoke include inoperative glow plugs, low engine compression, a bad injector spray pattern, injection pump problems, or late injection timing.

White smoke occurs mainly during cold starts, when the fuel tends to condense into liquid and does not burn due to cold engine parts.

Fig. 6-2

Normal Condition	Excessive Condition	Cause & Action
Blue-White Smoke: Can be observed during: Should not see	**Occurs During:** Acceleration Full Load Engine start up at all temps Low idle speeds after cold Start up During excessive idle	**Cause:** the presence of vaporized and unburned diesel fuel in the exhaust gas and lubricating oil in the exhaust gas. **Action:** Perform Performance test

Test	Pass	Fail	Action
Check Engine Oil Level: Check for contaminants Fuel, coolant Check for correct • Grade • Viscosity			Oil contaminated: • change oil and filter Wrong grade: • change oil and filter Wrong Viscosity: • change oil and filter
Boost Pressure: *Measure:* Pressure at full load & rated speed *Tool:* • Dash tachometer-30 PSI gauge • EST tool			Check manufacturer's specs for Vehicle being tested. *Check for the following:* • Restricted intake or exhaust • Low fuel pressure • Low injection control pressure • Control system faults • Defective injectors • Defective turbocharger • Base engine failure Repair/Replace as necessary, retest
Crankcase Pressure: Check manufacturers specs for Vehicle being tested. *Measure:* • Pressure at proper test point • High idle no load *Tool:* • Magnehelic gauge			Check manufacturers specs for Vehicle being tested. *Check for the following:* • Worn piston • Broken piston rings • Stuck piston rings • Worn or scored cylinder sleeves • Blown Air compressor head gasket • Worn Air compressor rings • Turbocharger seal failure • Excessive guide wear or leaking guide seals • Leaking intake manifold/valve cover gasket Repair/Replace as necessary, retest
Wastegate Actuator Test: Apply regulated air to actuator Inspect for: • Leakage • Actuator for movement *Tool:* • PSI gauge			Check manufacturer's specs for Vehicle being tested. *Check for the following:* • Sticky flapper valve • Ruptured actuator diaphragm • Leaky canister • Leaky hose to actuator

Refer to the smoke chart in section SEVEN

Black Smoke (High-Opacity Issues)

Root Cause & Condition:
Excessive black smoke results from a rich air-fuel mixture. This may stem from problems with the injection pump or injection timing. This could indicate; clogged air cleaner, worn fuel injectors, contaminated diesel fuel or a problem with the engine itself.

Fig. 6-3

Normal Condition	Excessive Condition	Cause & Action
Black Smoke: Can be observed during: Should not see	**Occurs During:** Start up Idle Acceleration Full load	**Cause:** soot, oil and un-burnt fuel **Action:** Perform Performance test

Test	Pass	Fail	Action
Check Engine Oil Level: Check for contaminants • Fuel, coolant Check for correct • Grade • Viscosity			Oil contaminated: • change oil and filter Wrong grade: • change oil and filter Wrong Viscosity: • change oil and filter
Fuel: Take sample from tank Inspect for contamination			If fuel contaminated: • drain and clean system • Replace all filters, change oil
Fuel Pressure: *Measure:* • Pressure at proper test point • Pressure at high idle • Pressure at Fuel Filter • Pressure at full load • Pressure at rated speed *Tool:* • Use proper tool: a gauge that reads At least 160psi			Check manufacturers' specs for vehicle being tested. Pressure low: • Inspect fuel lines • Replace filter • Clean strainer Retest
Intake Restriction Check filter minder (if equipped) *Measure:* • At high idle no loads *Spec:* 12.5ÒH20 Max. *Tool:* • Manometer or Magnehelic gauge •			Check manufacturers' specs for Vehicle being tested. If yellow band is latched @ 25ÓH20 • Replace filter Repair or replace all necessary components of air intake system to allow proper flow.
Exhaust Restriction: • Visually inspect exhaust system for damage *Measure:* • After turbo outlet (3"to 6") • Full load and rated speed *Tool:* Manometer or Magnehelic gauge			Check manufacturers' specs for Vehicle being tested. Damaged exhaust system: • Repair/Replace necessary components Fails to meet specs on test: • Replace necessary components Retest
Injector Control Pressure: Monitor pressure and engine rpm with EST *Check readings at:* • Low idle • High idle • Full load			Check manufacturers' specs for Vehicle being tested. If readings are out of specs, check for the following: Defective regulator valve Defective high pressure pump Injection control pressure system leakage ECM commanding a reduction in fuel pressure CHECK FOR: Low boost pressure Incorrect APS reading Incorrect feedback signal

Refer to the smoke chart in section SEVEN

Gray Smoke (Low-Opacity Issues)

Root Cause & Condition:

Gray smoke may occur at engine start-up whether or not the engine is at normal operating temperature. Gray smoke occurs at all ambient temperatures and should dissipate after 1-2 minutes of driving the vehicle.

Blue-white smoke can return when ambient temperature is below 10°C (50°F) and the engine has warmed up due to extended idling. This is due to the cooling of the combustion chambers that occurs during extended periods at idle. Heavy gray smoke may also occur at full throttle with the transmission in neutral or park. If continuous gray smoke occurs while driving, the fuel system is probably sucking air.

Fig. 6-4

Normal Condition	Excessive Condition	Cause & Action
Gray Smoke: Can be observed during: Should not see	**Occurs During:** Acceleration Full load	**Cause:** air induction system **Action:** Perform Performance test
Gray/Black Smoke: Can be observed during: Should not see	**Occurs During:** Acceleration Full load	**Cause:** consists of solid particles of carbon, i.e. soot, dirty fuel, lack of oil changes poor maintenance. **Action:** Perform Performance test

Test	Pass	Fail	Action
Intake Restriction: Check filter minder (if equipped) *Measure:* • At high idle no loads *Spec:* • 12.5ÒH20 Max. *Tool:* • Manometer or Magnehelic gauge			Check manufacturers' specs for Vehicle being tested. If yellow band is latched @ 25ÓH20 • Replace filter Repair or replace all necessary components of air intake system to allow proper flow.
Boost Pressure: *Measure:* Pressure at full load & rated speed *Tool:* • Dash tachometer and 0-30 PSI gauge • EST tool			Check manufacturers' specs for Vehicle being tested. *Check for the following:* • Restricted intake or exhaust • Low fuel pressure • Low injection control pressure • Control system faults • Defective injectors • Defective turbocharger • Base engine failure Repair/Replace as necessary, retest
Wastegate Actuator Test: Apply regulated air to actuator Inspect for: • Leakage • Actuator for movement *Tool:* • PSI gauge			Check manufacturers' specs for Vehicle being tested. *Check for the following:* • Sticky flapper valve • Ruptured actuator diaphragm • Leaky canister • Leaky hose to actuator
Valve Clearance: Check clearance with feeler gauge: • Engine Off • Hot or Cold			Check manufacturers' specs for Vehicle being tested. Adjust to manufacturers specs Cannot adjust to specs, check the following: • Worn valve train components • Valve seat or face wear

Refer to the smoke chart in section SEVEN

Typical Emission Standards

MODEL YEAR 1987 – 2003

Model year 1988-2003 US federal (EPA) and 1987-2003 California (ARB) emissions standards for heavy-duty diesel trucks and bus engines are summarized in the following tables. Applicable to the 1994 and following year standards, sulfur content in the certification fuel has been reduced to 500 ppm wt.

Fig. 6-1

EPA Emission Standards for Heavy-Duty Diesel Engines, g/bhp·hr				
Year	**HC**	**CO**	**NO_x**	**PM**
Heavy-Duty Diesel Truck Engines				
1988	1.3	15.5	10.7	0.60
1990	1.3	15.5	6.0	0.60
1991	1.3	15.5	5.0	0.25
1994	1.3	15.5	5.0	0.10
1998	1.3	15.5	4.0	0.10
Urban Bus Engines				
1991	1.3	15.5	5.0	0.25
1993	1.3	15.5	5.0	0.10
1994	1.3	15.5	5.0	0.07
1996	1.3	15.5	5.0	0.05*
1998	1.3	15.5	4.0	0.05*
* - in-use PM standard 0.07				

MODEL YEAR 2004 and Later

In October 1997, EPA adopted new emissions standards for model year 2004 and later heavy-duty diesel truck and bus engines. These standards reflect the provisions of the Statement of Principles (SOP) signed in 1995 by the EPA, California Air Resources Board, and the manufacturers of heavy-duty diesel engines. The goal was to reduce N0x emissions from highway heavy-duty engines to levels approximately 2.0 g/bhp hr beginning in 2004. Manufacturers have the flexibility to certify their engines to one of the two options shown below.

Fig. 6-2

EPA Emission Standards for MY 2004 and Later HD Diesel Engines, g/bhp·hr		
Option	**NMHC + NO_x**	**NMHC**
1	2.4	n/a
2	2.5	0.5

All emissions standards other than NMHC and N0x applying to 1998 and later model year heavy-duty engines (Fig. 7-1) will continue at their 1998 levels.

Model Year 2007 and Later

On December 21, 2000, the EPA signed emissions standards for model year 2007 and later heavy-duty highway engines (CARB adopted virtually identical 2007 heavy-duty engine standards in October 2001). The rule includes two components:

1. emissions standards
2. diesel fuel regulations

The first component of the regulations introduces new, very stringent emissions standards as follows:

PM – 0.01 g/bhp hr **N0x – 0.20 g/bhp hr** **NMHC – 0.14 g/bhp hr**

The PM emissions standard will take full effect in the 2007 heavy-duty engine model year. The N0x and NMHC standards will be phased in for diesel engines between 2007 and 2010. The phase in would be on a percent of sales basis:

50% from 2007 to 2009
100% in 2010

Effective 2007 model year, the regulation also eliminates the earlier crankcase emission control exception for turbocharged heavy-duty diesel engines. Crankcase emissions from these engines are treated the same as other exhaust emissions. Manufacturers are expected to control crankcase emissions by routing them back to the engine intake or to the exhaust upstream of the exhaust emission control devices.

STUDY QUESTIONS

<u>DIESEL EMISSIONS & SMOKE DIAGNOSTICS</u>

1. **<u>True or False</u> - Black smoke is usually an indicator that the engine is operating normally?**

2. **Black smoke can commonly be an indication of ___________________.**

   A. a plugged fuel filter

   B. low cylinder heat

   C. a plugged air filter

3. **Blue smoke indicates problems with _______________________.**

   A. injectors

   B. the turbocharger

   C. scored cylinder walls

   D. a bad computer

4. **The most common reasons for white smoke are**

   A. late injection timing

   B. a cold engine

   C. inoperative glow plugs

   D. All of the above

5. **Basic system checks of the <u>cooling system</u> should include____________.**

   A. verifying airflow and fuel pressure

   B. monitoring exhaust pressure and emissions

   C. testing and maintaining intake system piping

   D. scheduled maintenance and cleaning of cooling system

6. **Basic system checks of the <u>intake system</u> should include**

A. verifying airflow and fuel pressure

B. monitoring exhaust pressure and emissions

C. testing and maintaining intake system piping

D. scheduled maintenance and cleaning of cooling system

7. **Basic system checks of the <u>fuel injection system</u> should include**

A. monitoring exhaust temperatures

B. monitoring coolant temperatures

C. checking primary fuel pressure and leaks

D. none of the above

8. **Hard starting problems can be caused by ________________________.**

A. Bad glow plugs

B. Slow cranking speed

C. Neither A and B

D. Both A and B

9. **Low Power can be caused by ______________________________.**

A. plugged air filter

B. plugged fuel filter

C. tank cap vent plugged

D. all of the above

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Troubleshooting Charts

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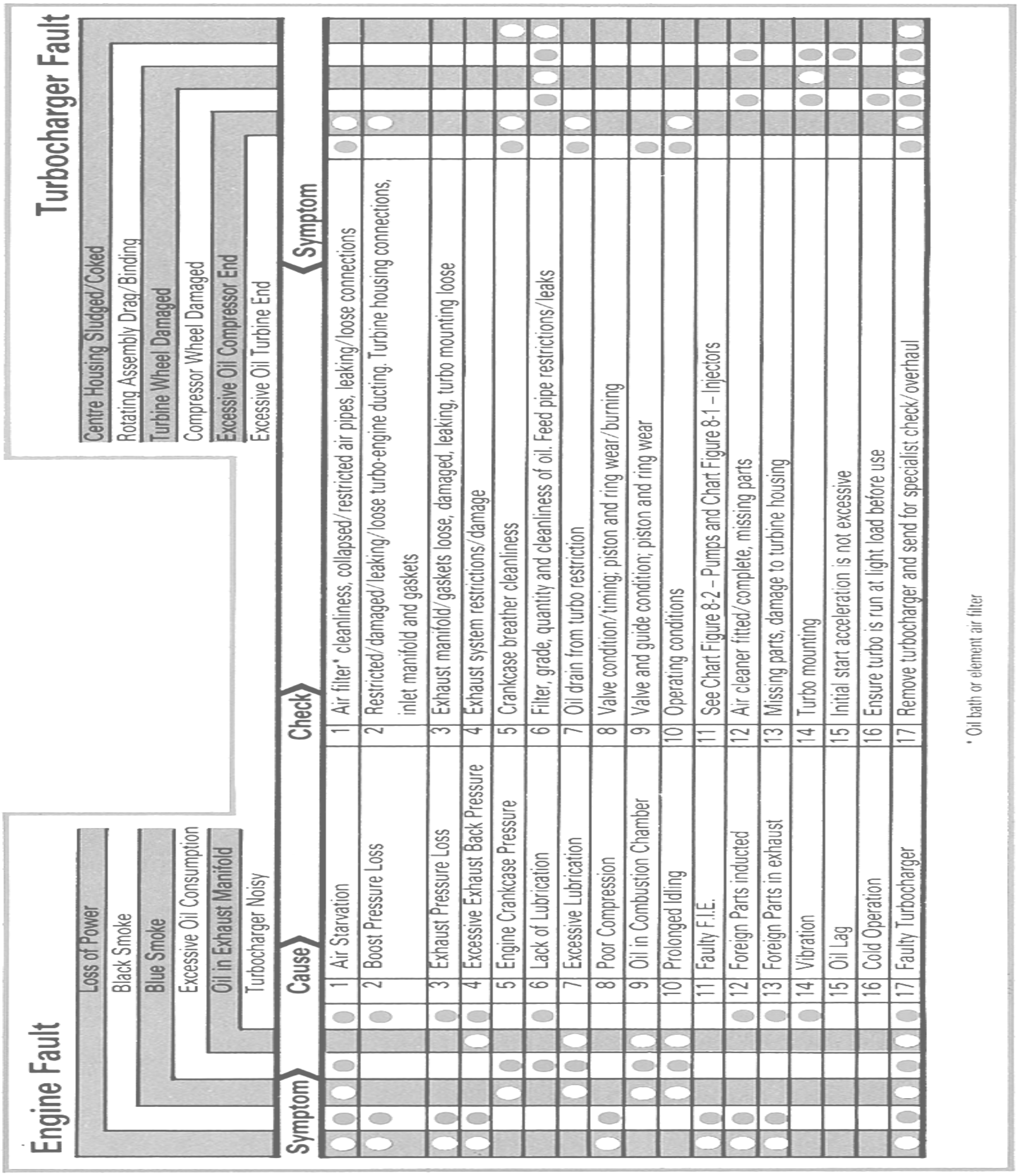
Turbochargers/Intercoolers

Fig. 7-1



Fuel Injectors

Fig. 7-2a

	Cause	Check	Cylinder Knock — Uneven Running — Misfire	Loss of Power — Excessive Consumption	Engine Overheating	Black Smoke	Poor Starting
1	Injector not sealing in cylinder head	For cleanliness and sealing washers if specified	●	●			●
2	Two sealing washers under injector	Number of washers and if specified	●	●	●	●	●
3	High pressure pipe joint leaks	Pipe unions for leaks	●	●			●
4	Back leak pipe joint leaks	Unions for leaks		●			
5	High pressure pipe restricted	High pressure pipe bores	●				
6	Injector sticking	Fixing nuts or bolts are accurately torqued with correct washer	●	●	●	●	●
7	Incorrect injectors fitted	Manufacturer's specification	●	●	●	●	●
8	Injector faulty	Check injector on a nozzle setting outfit	●	●	●	●	●

Removing Injectors — Always ensure that injectors are not knocked during removal particularly pintaux nozzles as the valve tips can easily be damaged. Impact extractors are available from your Delphi CAV agent.

Fitting Injectors — Ensure injector, cylinder head bore and seat are clean. Check manufacturer's specification is observed for fitment of sealing washer and heat shield. Tighten fixing bolts or nuts evenly to the correct torque.

If nozzle body or valve is worn or damaged the nozzle must be replaced or sent for specialist repair.

Fuel Injectors

Fig. 7-2b

Back Leakage	Opening Pressure	Atomisation	Seat Tightness	Cause	Check
●				1 Pressure face leak	1 Nozzle cap nut torque and pressure faces clean and undamaged
●				2 Nozzle valve scored or having excessive clearance	2 Valve stem and nozzle body visually
	○	●		3 Incorrect setting	3 Opening pressure and reset if necessary
	○	●	○	4 Nozzle seized or sticking	4 For foreign matter, distortion or damage
	○	●		5 Spray holes blocked	5 Holes are free of carbon
●	○	●	○	6 Valve not seating	6 Nozzle valve and body for carbon pitting or damage
	○	●		7 Broken or distorted spring	7 Spring visually and replace if necessary
	○	●		8 Auxiliary hole blocked	8 Hole is free of carbon
		●		9 Pintle broken or damaged	9 Nozzle valve tip visually for damage
	○	●		10 Nozzle holder spindle worn	10 Spindle ends for wear and replace if necessary
	○	●	○	11 Nozzle cap nut overtightened	11 Cap nut torque

Removing Injectors — Always ensure that injectors are not knocked during removal particularly pintaux nozzles as the valve tips can easily be damaged. Impact extractors are available from your Delphi CAV agent.

Fitting Injectors — Ensure injector, cylinder head bore and seat are clean. Check manufacturer's specification is observed for fitment of sealing washer and heat shield. Tighten fixing bolts or nuts evenly to the correct torque.

If nozzle body or valve is worn or damaged the nozzle must be replaced or sent for specialist repair.

Fuel Pumps (Fuel Distributors)

Fig. 7-3a

Difficult Starting	Irregular Idle and Fast Idle	Insufficient Maximum Speed	Erratic Running/Surging	Excessive Smoke	Excessive Noise	Lack of Power	Excessive Fuel Consumption	Stalling	Slow Engine Die-down	Engine cannot be Shut Off	Cause	Check
●			●								1 Lack of fuel	1 Fuel level
●											2 Manual stop control* faulty	2 In run position and linkage free
●			●							●	3 Stop solenoid* faulty	3 Audible operation when switched. Check electrical supply
										●	4 Stop solenoid* valve leaking	4 Engine stops when supply lead removed
●											5 Wrong starting procedure	5 Starting procedure correct. (Start advance and starting aid operation)
●	●	●	●			●		●			6 Air in fuel system	6 Fuel system is vented, all joints and unions airtight, no leakage at diaphragms
●	●	●	●			●		●			7 Fuel inlet restriction	7 Filter not choked and feed pipes clear
●	●	●		●		●		●			8 Fuel contamination	8 Diesel fuel being used, not petrol; free of water, dirt, ice and wax
●											9 Low cranking speed	9 Battery, starter, cable connections. Correct engine lubricating oil
●				●			●				10 Starting aid* ineffective (Plugs or Thermostart)	10 Correct functioning. Fuel supply* and electrical connections
●	●		●	●	●	●	●	●			11 Injection timing incorrect	11 Pump to engine timing
●											12 Timing belt* slipped several teeth	12 Belt condition and tension
●	●	●				●					13 Feed pump* faulty	13 Feed pump pressure

* if fitted

Fuel Pumps (Fuel Distributors)

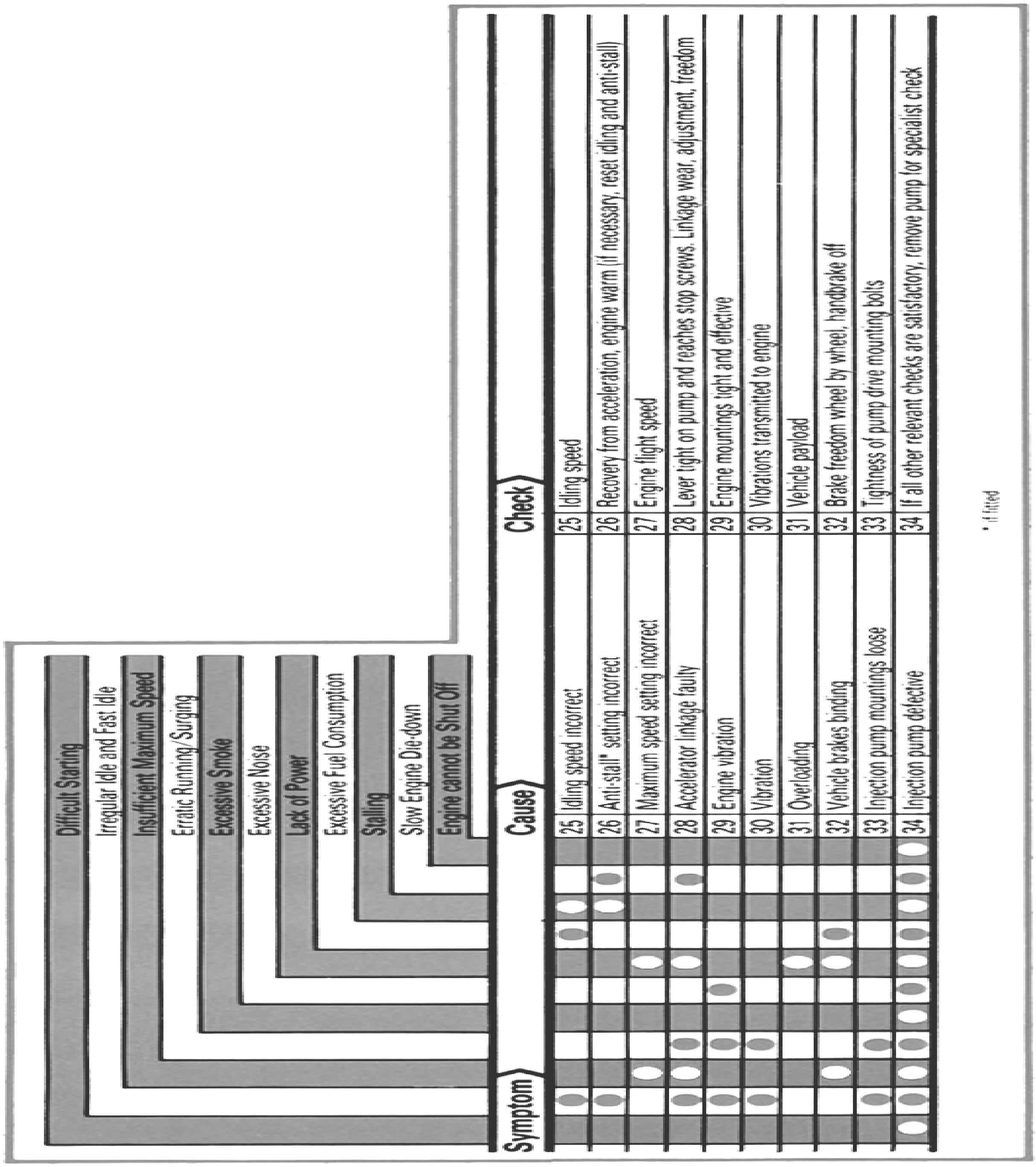
Fig. 7-3b

Difficult Starting	Irregular Idle and Fast Idle	Insufficient Maximum Speed	Erratic Running/Surging	Excessive Smoke	Excessive Noise	Lack of Power	Excessive Fuel Consumption	Stalling	Slow Engine Die-down	Engine cannot be Shut Off	Cause	Check
●	●	●				●		●			14 Fuel return restricted	14 Rotary pump backleak, tank returns, filter vents are clear
●	●	●	●			●					15 Fuel circuit incorrect	15 Inlet and backleak pipes correct way round. Banjo bolts of correct CAV type
●	●	●	●		●	●	●	●			16 Engine condition	16 Cylinder compression. Valve timing and clearances. Air filter not choked. Injector seating
						●	●				17 Exhaust system defective	17 System unrestricted
●	●		●		●	●	●				18 Fuel atomisation	18 Injectors: correct type, opening pressure, spray condition, evenly tightened
●	●		●			●					19 Fuel tank blockage	19 Tank vent and outlet filter unrestricted
●	●	●	●			●	●				20 HP pipe type/firing order incorrect	20 HP pipes type and fitted in correct firing order
	●		●			●					21 HP pipe restriction	21 HP pipes not kinked or bore reduced at nipples
●	●		●			●	●	●			22 HP vent* leaking	22 Vent screw tight
●	●		●			●	●				23 HP pipe leaking	23 HP pipe joint tightness
						●	●				24 LP leakage	24 Feed and return pipes, filter, feed pump and tank for leakage

* if fitted

Fuel Pumps (Fuel Distributors)

Fig. 7-3c



Smoke Diagnosis Chart

Fig. 7-4

Speed	Black/Dark Grey at full load	Black/Dark Grey at high load	Black/Dark Grey any load	Blue/White at light load	Blue at light load/acceleration	Blue any load		Cause		Check
Maximum	●						1	Overspeeding	1	Max speed setting
						●	2	Lub oil induction	2	Oil bath air cleaner for overfilling
	●						3	Choked Venturi	3	Venturi (pneumatic governor) is not restricted
Medium to Maximum	●						4	Retarded timing	4	Pump to engine timing, auto advance function
	●	●					5	Incorrect atomisation	5	Injectors — see chart
	●						6	Air starvation	6	Air cleaner: ducting restrictions; turbo operation
	●						7	HP Pipes	7	Bore size; length; restrictions
					●		8	Cold engine	8	Thermostat: cooling system, operation
Low to Medium	●						9	Advanced Timing	9	Pump to engine timing; auto advance function
		●					10	Poor compression	10	Setting/condition of valves, piston rings + air intake
All	●						11	Overfuelling	11	FI Pump, excess fuel device — see chart
	●		●	●			12	Incorrect atomisation	12	Injector type/setting/condition — see chart
			●				13	Poor combustion	13	Injector fitment — see chart
				●			14	Retarded timing	14	Pump to engine timing; auto advance function
						●	15	Lub oil passing pistons	15	Piston/ring/bore condition
					●		16	Lub oil passing valves	16	Valve stem/guide condition

Common-Sense Approach To Diesel Emissions

Diesel Emissions

Diesel Engine Operation

Power, Fuel Economy & Low Emissions

Electronic Control of Diesel Emissions

Understanding & Using Scan Data

Diesel Emissions & Smoke Diagnostics

Troubleshooting Charts

Study Questions Answer Key

Glossary

EIGHT

ANSWER KEY

ONE - <u>DIESEL EMISSIONS</u>

1. C. 0.1 micron (Nano paticles)

2. C. diesel engines produce much higher levels of NO_X and particulate matter to the atmosphere.
   atmosphere.

3. D. All of the above
   asthma attacks chronic bronchitis
   coughing difficulty breathing
   lowered resistance to infection premature death

4. C. a diesel engine produces lower levels of HC and CO than a gasoline engine

5. C. 2.5 microns

TWO - <u>DIESEL ENGINE OPERATION</u>

1. B. Direct Injection Chamber

2. True

3. True

THREE - <u>POWER, FUEL ECONOMY & LOW EMISSIONS</u>

1. C. 30 to 40 %

2. C. programmable for optimal performance over the entire engine's speed range

3. C. adding a forced induction device such as a turbocharger

4. C. allows a smaller turbo to be used to reduce lag

5. Yes

6. A. fuel rail pressure for precise fuel delivery

7. D. Both A and C
   storing the fuel under extremely high pressure in central accumulator rail

   delivering the fuel to the individual electronically-controlled injectors on demand

8. B. perform and enhance the EGR function and help improve catalyst heating

9. D. Wall-Flow Monoliths

10. C. routing these gases into the air intake system

11. Yes

12. True

13. True

14. B. better turbocharger performance and lower fuel consumption

FOUR-<u>ELECTRONIC CONTROL OF DIESEL EMISSIONS</u>

1. D. All of the above
   Input and output values
   Component locations and wiring schematics
   A way of accessing information shared between the ECM and sensors

2. D. All of the above
   Oil Pressure
   Manifold Absolute Pressure
   Barometric Pressure

3. A. Yes

4. D. an analog voltage signal that is proportional to the position of a mechanical device

5. True

6. C. Read-Only Memory (ROM)

FIVE - <u>UNDERSTANDING & USING SCAN DATA</u>

1. C. the controller sending the message

2. D. Both A and B
   Message Identifiers (MIDs)
   Subsystem Identifiers (SIDs)
   Parameter Identifiers (PIDs)
   Failure Mode Identifiers (FMIs)

3. D. All of the above
   engine/vehicle speed
   engine load
   overall system condition

SIX - <u>DIESEL EMISSIONS & SMOKE DIAGNOSTICS</u>

1. False

2. C. a plugged air filter

3. C. scored cylinder walls

4. D. All of the above
   inoperative glow plugs
   a cold engine
   late injection timing

5. D. scheduled maintenance and cleaning of cooling system

6. C. testing and maintaining intake system piping.

7. C. checking primary fuel pressure and leaks

8. D. Both A and B
   Bad glow plugs
   Slow cranking speed

9. D. all of the above
   plugged air filter
   plugged fuel filter
   tank cap vent plugged

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NINE

GLOSSARY OF TERMS

A

Additives
Chemicals added to fuel in very small quantities to improve and maintain fuel quality and/or to lower emissions.

Adsorber
The surface of a solid or liquid body to which an extremely thin layer of molecules (gas, solutes or liquid) will adhere when the latter comes into contact.

Aftercooling / Intercooling
Cooling the engine intake air after the turbocharger and prior to introduction into the cylinder. Aftercooling increases engine power and lowers NOx emissions.

Aftertreatment Devices
Devices which remove pollutants from exhaust gases after the gas leaves combustion chamber (e.g., catalytic converters or diesel particulate filters). Also referred to as "post-combustion treatment" or "exhaust emission control."

American Society for Testing and Materials (ASTM)
A non-profit organization that establishes specifications and standard test methods for a broad range of materials and products. ASTM standards are recognized as definitive guidelines for quality of motor fuels.

B

Biodiesel
The mono alkyl esters of long chain fatty acids derived from renewable lipid feedstocks, such as vegetable oils and animal fats, for use in compression ignition (diesel) engines. Manufactured by transestrification of the organic feedstock by methanol.

C

California Air Resources Board (CARB)
A state regulatory agency charged with regulating the air quality in California.

Carbon Dioxide (CO2)
A colorless, odorless, non-toxic gas. It is one of main products of fossil-fuel combustion. Carbon dioxide is a greenhouse gas that contributes to the potential for global warming.

C

Carbon Monoxide (CO)
A colorless, odorless and toxic gas. It blocks the lungs' ability to obtain oxygen. CO is produced by incomplete combustion of fossil fuels and is a major part of air pollution. Compression ignition (diesel) engines generate significantly lower CO emissions than spark ignited engines.

Carcinogens
Substances known to cause cancer.

Catalyst
A substance which influences the rate of a chemical reaction but is not one of the original reactants or final products, i.e. it is not consumed or altered in the reaction. Catalysts are used in many processes in the chemical and petroleum industries. Emission control catalysts are used to promote reactions that change exhaust pollutants from internal combustion engines into harmless substances.

Cetane Index
A calculated value, derived from fuel density and volatility, giving a reasonably close approximation to cetane number.

Cetane Number
A measure of ignition quality of diesel fuel. The higher the cetane number the easier the fuel ignites when injected into an engine. Cetane number is determined by an engine test using two reference fuel blends of known cetane numbers. The reference fuels are prepared by blending normal cetane (n-hexadecane), having a value of 100, with heptamethyl nonane, having a value of 15.

Clean Air Act (CAA)
In the U.S., the fundamental legislation to control air pollution. The original Clean Air Act was signed in 1963. The law set emissions standards for stationary sources, such as factories and power plants. Criteria pollutants included lead, ozone, CO, SO2, NOx and PM, as well as air toxics. The CAA was amended several times, most recently in 1990. The Amendments of 1970 introduced motor vehicle emission standards for automobiles and trucks.

Clean-Fuel Vehicle (CFV)
A vehicle that has been certified to meet clean-fuel standards of the Clean Air Act Amendments of 1990.

Cloud Point (CP)
A measure of the ability of a diesel fuel to operate under cold weather conditions. Defined as the temperature at which wax first becomes visible when diesel fuel is cooled under standardized test conditions (ASTM D2500).

C

Common Rail Injection

A diesel fuel injection system employing a common pressure accumulator, called the rail, which is mounted along the engine block. The rail is fed by a high pressure fuel pump. The injectors, which are fed from the common rail, are activated by solenoid valves. The solenoid valves and the fuel pump are electronically controlled. In the common rail injection system the injection pressure is independent from engine speed and load. Therefore, the injection parameters can be freely controlled. Usually a pilot injection is introduced, which allows for reductions in engine noise and NOx emissions.

Compression Ignition (CI)

The form of ignition that initiates combustion in a diesel engine. The rapid compression of air within the cylinders generates the heat required to ignite the fuel as it is injected.

D

Depth Filtration Mechanisms

Depth Filtration involves trapping particulates within the volume of the filter material. Filters sheets are essentially a maze of paper fibers. Particulates penetrate the entire volume of the paper until they reach a dead end and are trapped.

Diesel Oxidation Catalyst (DOC)

Catalyst promoting oxidation processes in diesel exhaust. Usually designed to reduce emissions of the organic fraction of diesel particulates, gas-phase hydrocarbons, and carbon monoxide.

Diesel Particulate Filter (DPF)

A device that physically captures diesel particulates preventing their discharge from the tailpipe. Collected particulates need to be removed from the filter, usually by continuous or periodic oxidation in a process called "regeneration."

Diesel Particulate Matter (DPM)

Sub-micron size particles found in diesel exhaust. Most emission regulations specify DPM measurement methods in which particulates are sampled on filters from cooled exhaust gas. The cooling causes condensation of vapors in the gas sampling train. Thus, the DPM is composed of both solid and liquid particles and is generally classified into three fractions: (1) inorganic carbon (soot), (2) organic fraction (often referred to as SOF or VOF), and (3) sulfate fraction (hydrated sulfuric acid).

Dimethyl Ether (DME)

The simplest ether CH3-O-CH3. Can be manufactured from natural gas or from a renewable organic feedstock. DME is a prospective alternative diesel fuel.

D

Direct Injection (DI)

In diesel engines with direct injection the combustion chamber is not divided and fuel is injected directly to the cylinder.

E

Electronic Control Module (ECM)

A microprocessor that determines the beginning and end of each injection cycle on every cylinder. The ECM determines both fuel metering and injection timing in response to such parameters as engine crankshaft position and RPM, engine coolant and intake air temperature, and absolute intake air boost pressure.

Electronic Driver Unit (EDU)

A high gain/impedance electrical circuit used to control a high current output device in an electronic circuit.

Elemental Carbon (EC)

Inorganic carbon, as opposed to carbon in organic compounds, sometimes used as a surrogate measure for diesel particulate matter, especially in occupational health environments. Elemental carbon usually accounts for 40-60% of the total DPM mass.

Emission Credit Trading

A program administered by the Environmental Protection Agency under which low polluters are awarded credits which may be traded on a regulated market and purchased by polluters who are in noncompliance for emissions until compliance can be achieved.

EPACT

The U.S. Energy Policy Act of 1992.

F

Federal Test Procedure (FTP)

Test cycle(s) used in the U.S. for emission testing and certification of engines and vehicles. The chassis dynamometer cycle for light duty vehicle testing is commonly referred to as FTP-75. The engine dynamometer cycle for testing of heavy-duty (HD) engines is known as HD FTP, or FTP Transient cycle.

Flash Point

The temperature at which a combustible liquid gives off just enough vapor to produce a vapor/air mixture that will ignite when a flame is applied. The flash point is measured in a standardized apparatus using standard test methods, such as ASTM D93 or ISO 2719.

G

Gas Turbine
A turbine powered by a gas, such as the hot gas produced in combustion processes.

H-L

Hydromechanical Injection
An injection system in which mechanical parts work through hydraulic pressure to meter and time the injection of fuel. No electronics are incorporated into hydromechanical injection systems.

Ignition Delay
The length of time or number of degrees of crankshaft rotation between the beginning of injection and ignition of the fuel.

In-Direct Injection (IDI)
In diesel engines with indirect injection the fuel is injected to an auxiliary pre-chamber. Combustion starts in the prechamber and propagates to the cylinder.

Injection Period
The time, measured in degrees of crankshaft rotation, between the beginning and end of injection. On engines with hydromechanical injection systems, it is controlled by the opening and closing of ports in the injector body or by the action of a plunger forcing fuel out of a cup. On electronic injection systems, it is determined directly or indirectly by the action of a solenoid valve.

In-Line Injection Pump
An injection pump with a separate cylinder and plunger for each engine cylinder. Each plunger is rotated by a rack to determine metering via ports in the body of the pump and helical cuts on the pump plungers. The plungers are driven off a camshaft, which usually incorporates a centrifugal or electronically controlled timing advance mechanism.

Lean NOx Catalyst (LNC)
Catalyst designed to reduce nitrogen oxides from diesel or spark-ignited engine exhaust gases under net oxidizing conditions, i.e., in the presence of excessive amount of oxygen.

Low Emission Vehicle (LEV)
A vehicle that is certified to meet the LEV emission standards set by the California Air Resources Board (CARB).

N

National Ambient Air Quality Standards (NAAQS)
Ambient standards for six pollutants including ozone, carbon monoxide, nitrogen dioxide, lead, particulate matter, and oxides of sulfur specifically regulated under the U.S. Clean Air Act of 1990. Urban areas are required to achieve attainment in regards to ambient concentrations of these criteria pollutants.

Nitrogen Oxides (NOx)
Several air-polluting gases composed of nitrogen and oxygen which play an important role in the formation of photochemical smog. Nitrogen oxides are collectively referred to as "NOx", where "x" represents a changing proportion of oxygen to nitrogen. Internal combustion engines are significant contributors to the worldwide nitrogen oxide emissions. For the purpose of emission regulations, NOx is composed of colorless nitric oxide (NO), and the reddish-brown, very toxic and reactive nitrogen dioxide (NO2). Other nitrogen oxides, such as nitrous oxide N2O (the anesthetic "laughing gas"), are not regulated emissions.

O

On-Board Diagnostics (OBD)
A system on board of the vehicle that monitors emission control components and alerts the driver (e.g., by a dashboard light) if malfunctions or emission deterioration occurs. The OBD system involves a number of sensors and a data processor, which is typically integrated with the vehicle's electronic management system.

Opacity Meter
A type of meter that uses the transmission of a beam of light to measure the opacity or density of a plume or sample of smoke.

Opacity
The percentage of light transmitted by a light source that is prevented from reaching a light detector.

Original Equipment Manufacturer (OEM)
Manufacturers of equipment (such as engines, vehicles, etc.) that provide the original product design and materials for its assembly and manufacture. OEMs are directly responsible for manufacturing and modifying the products, making them commercially available, and providing the warranty.

Overhead Cam
A camshaft used for operating both valves and unit injectors, located on top of or within the cylinder head. Such camshafts are driven by a multi-gear gear train off the crankshaft. They simplify the design of the cylinder head and eliminate pushrods, allowing for much larger, open intake and exhaust ports and better breathing.

O

Oxygenated Fuel

Any fuel substance containing oxygen, such as ethanol, methanol, or biodiesel. Oxygenated fuel tends to give a more complete combustion of its carbon into carbon dioxide (CO_2), thereby reducing emissions of hydrocarbons and carbon monoxide. Oxygenated fuels may result in increased nitrogen oxides emissions.

Oxygen Storage Capacity (OSC)

A capacity of the catalyst washcoat to store oxygen at lean and to release it at rich condition. Typically provided by cerium oxide (ceria), which oscillates between an oxidized and reduced state, depending on the exhaust gas chemistry. The OSC is an important component of three-way catalysts, used to extend the catalyst window.

P

Particulate Matter (PM)

Particles formed by incomplete combustion of fuel. Compression ignition (diesel) engines generate significantly higher PM emissions than spark ignited engines. The particles are composed of elemental carbon, heavy hydrocarbons (SOF), and hydrated sulfuric acid ("sulfate particulates").

Petroleum

A generic term applied to oil and oil products in all forms. Examples include crude oil, lease condensate, unfinished oil, refined petroleum products, and natural gas plant liquids.

Precombustion Chamber

A small, auxiliary combustion chamber connected by a narrow orifice with the main chamber. Fuel is injected into the pre-chamber and ignites there, causing hot gases to expand into the main chamber (cylinder).

Pump-In-Line-Nozzle Fuel System

A fuel system using a single injection pump driven off the gear train on the front of the engine that also drives the camshaft. The central injection pump feeds a separate injection nozzle located in the cylinder head above each cylinder. Lines which must be of exactly equal length link each pump plunger with the associated nozzle. Each nozzle incorporates a needle valve and the orifices which actually handle atomization.

R

Rotary Injection Pump

A lower-cost injection pump used with pump-line-nozzle systems. The pump has a central plunger system (usually consisting of two opposing plungers) that provides fuel to every cylinder during the required injection period. A plate located near the top of the pump rotates, opening an appropriate orifice at the right time for distribution to each cylinder's injection nozzle through a separate line. It is usually used with automotive or agricultural engines that have lower performance and durability requirements than the heavy-duty truck diesels.

S

SAE
Society of Automotive Engineers

Soluble Organic Fraction (SOF)
The organic fraction of diesel particulates. SOF includes heavy hydrocarbons derived from the fuel and from the engine lubricating oil. The term "soluble" originates from the analytical method used to measure SOF which is based on extraction of particulate matter samples using organic solvents.

Supercharger
A compressor device to compress the combustion air or the air/fuel mixture before it enters the engine cylinder. Superchargers are typically driven by the engine itself, through a system of gears, a belt drive, or by an electrical motor.

Swirl Combustion
A combustion chamber configuration which uses curved mixing ridges in the intake ports and/or a re-entrant piston bowl (a bowl whose top edges curve inward). Some swirl combustion chambers have a larger rim around the outside of the piston and a more compact combustion chamber or bowl. The swirl is used to reduce particulate emissions.

T

TMC
The Maintenance Council of the American Trucking Association

Thermal Degradation
Molecular deterioration of materials such as resins and organic fibers because of overheating. It occurs at a temperature at which some components of the material are separating or reacting with one another to modify the macro- or microstructure.

Total Carbon (TC)
The sum of the elemental carbon and organic carbon associated with diesel particulates. Typically amounts to 80-85% of the total DPM mass.

Total Particulate Matter (TPM)
The total particulate matter emissions including all fractions of diesel particulates, i.e. the carbonaceous, organic (SOF), and sulfate particulates.

Turbine
A rotary machine which extracts mechanical shaft power from the working fluid (gas or liquid) using rotor vanes.

Turbocharging
A process of compressing the engine intake air charge to allow more air and fuel into the cylinder thus, increasing the engine power output. The compressor, called the turbocharger, is driven by an exhaust gas propelled turbine.

T

Turbo Generator
Gas turbine combined with an electrical generator.

Turbo Lag
The time delay between injecting fuel to accelerate and delivering air to the intake manifold by the turbocharger. This phenomenon may cause black smoke emissions in some turbocharged diesel engines during acceleration.

U – W

Unit Injector
An injector which is camshaft-driven and incorporates a plunger. The plunger works in conjunction with orifices in the injector body to determine the beginning and end of injection. The plungers has a helix and is rotated by a rack so the beginning and end of injection can occur closer together or farther apart, thus shortening or lengthening the injection period and changing metering. A special pump which supplies fuel through an orifice to the injector operates at a pressure which is precisely controlled depending on the changes in engine speed.

Volatile Organic Compounds (VOC)
Hydrocarbon-based emissions released through evaporation or combustion. The term VOC is usually used in regard to stationary emission sources.

Volatile Organic Fraction (VOF)
The organic fraction of diesel particulate matter as determined by vacuum evaporation. It may or may not be equivalent to the SOF fraction. Depending on the exact analytical procedure, the VOF may include the organic material (SOF) as well as some of the sulfate particulates which, being composed primarily of hydrated sulfuric acid, are also volatile.

White Smoke
The smoke emitted during a cold start from a diesel engine, composed mainly of unburned fuel and particulate matter.