LEARNING OBJECTIVES: After studying this chapter, the reader should be able to: • State the characteristics of diesel engines. • Describe the fuel tank, lift pump, injection pump, and engine-driven vacuum pump. • Explain the HEUI system. • Discuss the purpose of glow plugs, diesel fuel heaters, diesel injector nozzles, and accelerator pedal position sensors. • Explain the purpose of diesel engine turbochargers. • Discuss the purpose of the exhaust gas recirculation system, selective catalytic reduction, and diesel oxidation catalysts. • Explain diesel particulate matter, and discuss the function of diesel exhaust particulate filters. • Discuss diesel exhaust smoke diagnosis. • Discuss compression testing, glow plug resistance balance test, injector pop testing, and diesel emission testing.

KEY TERMS: Diesel exhaust fluid (DEF) 119 • Diesel exhaust particulate filter (DPF) 117 • Diesel oxidation catalyst (DOC) 116 • Differential pressure sensor (DPS) 118 • Direct injection (DI) 107 • Glow plug 112 • Heat of compression 105 • High-pressure common rail (HPCR) 110 • Hydraulic electronic unit injection (HEUI) 110 • Indirect injection (IDI) 107 • Injection pump 105 • Lift pump 108 • Pop tester 122 • Particulate matter (PM) 116 • Opacity 122 • Regeneration 117 • Selective catalytic reduction (SCR) 119 • Soot 116 • Urea 119 • Water-fuel separator 108

DIESEL ENGINE OPERATION AND DIAGNOSIS

FUNDAMENTALS In 1892, a German engineer named Rudolf Diesel perfected the compression ignition engine that bears his name. The diesel engine uses heat created by compression to ignite the fuel, so it requires no spark ignition system.

The diesel engine requires compression ratios of 16:1 and higher. Incoming air is compressed until its temperature reaches about 1,000°F (540°C). This is called heat of compression. As the piston reaches the top of its compression stroke, fuel is injected into the cylinder, where it is ignited by the hot air. SEE FIGURE 11–1.

As the fuel burns, it expands and produces power. Because of the very high compression and torque output of a diesel engine, it is made heavier and stronger than the same size gasoline-powered engine.

A diesel engine uses a fuel system with a precision injection pump and individual fuel injectors. The pump delivers fuel to the injectors at a high pressure and at timed intervals. Each injector sprays fuel into the combustion chamber at the precise moment required for efficient combustion. SEE FIGURE 11–2.

ADVANTAGES AND DISADVANTAGES A diesel engine has several advantages compared to a similar size gasoline-powered engine, including:

1. More torque output
2. Greater fuel economy
3. Long service life

A diesel engine has several disadvantages compared to a similar size gasoline-powered engine, including:

1. Engine noise, especially when cold and/or at idle speed
2. Exhaust smell
3. Cold weather startability

FIGURE 11–1 Diesel combustion occurs when fuel is injected into the hot, highly compressed air in the cylinder.
In a diesel engine, air is not controlled by a throttle as in a gasoline engine. Instead, the amount of fuel injected is varied to control power and speed. The air-fuel mixture of a diesel engine can vary from as lean as 85:1 at idle to as rich as 20:1 at full load. This higher air-fuel ratio and the increased compression pressures make the diesel more fuel efficient than a gasoline engine, in part because diesel engines do not suffer from throttling losses. Throttling losses involve the power needed in a gasoline engine to draw air past a closed or partially closed throttle.

4. Vacuum pump that is needed to supply the vacuum needs of the heat, ventilation, and air-conditioning system
5. Heavier than a gasoline engine
6. Fuel availability
7. Extra cost compared to a gasoline engine

**CONSTRUCTION** Diesel engines must be constructed heavier than gasoline engines because of the tremendous pressures that are created in the cylinders during operation. **SEE CHART 11–1.** The torque output of a diesel engine is often double or more than the same size gasoline-powered engines.

**AIR-FUEL RATIOS** In a diesel engine, air is not controlled by a throttle as in a gasoline engine. Instead, the amount of fuel injected is varied to control power and speed. The air-fuel mixture of a diesel engine can vary from as lean as 85:1 at idle to as rich as 20:1 at full load. This higher air-fuel ratio and the increased compression pressures make the diesel more fuel efficient than a gasoline engine, in part because diesel engines do not suffer from throttling losses. Throttling losses involve the power needed in a gasoline engine to draw air past a closed or partially closed throttle.
In a gasoline engine, the speed and power are controlled by the throttle valve, which controls the amount of air entering the engine. Adding more fuel to the cylinders of a gasoline engine without adding more air (oxygen) will not increase the speed or power of the engine. In a diesel engine, speed and power are not controlled by the amount of air entering the cylinders because the engine air intake is always wide open. Therefore, the engine always has enough oxygen to burn the fuel in the cylinder and will increase speed (and power) when additional fuel is supplied.

**NOTE:** Many newer diesel engines are equipped with a throttle valve. This valve is used by the emission control system and is not designed to control the speed of the engine.

**INDIRECT AND DIRECT INJECTION** In an indirect injection (abbreviated IDI) diesel engine, fuel is injected into a small prechamber, which is connected to the cylinder by a narrow opening. The initial combustion takes place in this prechamber. This has the effect of slowing the rate of combustion, which tends to reduce noise. [See Figure 11–5.]

All indirect injection diesel engines require the use of a glow plug which is an electrical heater that helps start the combustion process.

In a direct injection (abbreviated DI) diesel engine, fuel is injected directly into the cylinder. The piston incorporates a depression where initial combustion takes place. Direct injection diesel engines are generally more efficient than indirect injection engines, but have a tendency to produce greater amounts of noise. [See Figure 11–6.]

While some direct injection diesel engines use glow plugs to help cold starting and to reduce emissions, many direct injection diesel engines do not use glow plugs.

**DIESEL FUEL IGNITION** Ignition occurs in a diesel engine by injecting fuel into the air charge, which has been heated by compression to a temperature greater than the ignition point of the fuel or about 1,000°F (538°C). The chemical reaction of burning the fuel creates heat, which causes the gases to expand, forcing the piston to rotate the crankshaft. A four-stroke diesel engine requires two rotations of the crankshaft to complete one cycle.

- On the intake stroke, the piston passes top dead center (TDC), the intake valve(s) opens, and filtered air enters the cylinder, while the exhaust valve(s) remains open for a few degrees to allow all of the exhaust gases to escape from the previous combustion event.
- On the compression stroke, after the piston passes BDC, the intake valve(s) closes and the piston travels up to TDC (completion of the first crankshaft rotation).
- On the power stroke, the piston nears TDC on the compression stroke and diesel fuel is injected into the cylinder, creating a chemical reaction that produces heat and expansion, forcing the piston to rotate the crankshaft.

![Figure 11–4](image-url) A rod/piston assembly from a 5.9 liter Cummins diesel engine used in a Ram pickup truck.

![Figure 11–5](image-url) An indirect injection diesel engine uses a prechamber and a glow plug.

![Figure 11–6](image-url) A direct injection diesel engine injects the fuel directly into the combustion chamber. Many designs do not use a glow plug.
cylinder by the injectors. The ignition of the fuel does not start immediately but the heat of compression starts the combustion phases in the cylinder. During this power stroke, the piston passes TDC and the expanding gases force the piston down, rotating the crankshaft.

- On the exhaust stroke, as the piston passes BDC, the exhaust valve(s) opens and the exhaust gases start to flow out of the cylinder. This continues as the piston travels up to TDC, pumping the spent gases out of the cylinder. At TDC, the second crankshaft rotation is complete.

### THREE PHASES OF COMBUSTION

There are three distinct phases or parts to the combustion in a diesel engine.

1. **Ignition delay.** Near the end of the compression stroke, fuel injection begins, but ignition does not begin immediately. This period is called *ignition delay*.

2. **Rapid combustion.** This phase of combustion occurs when the fuel first starts to burn, creating a sudden rise in cylinder pressure. It is this sudden and rapid rise in combustion chamber pressure that causes the characteristic diesel engine knock.

3. **Controlled combustion.** After the rapid combustion occurs, the rest of the fuel in the combustion chamber begins to burn and injection continues. This process occurs in an area near the injector that contains fuel surrounded by air. This fuel burns as it mixes with the air.

### FUEL TANK AND LIFT PUMP

**PARTS INVOLVED** A fuel tank used on a vehicle equipped with a diesel engine differs from the one used with a gasoline engine in the following ways.

- The filler neck is larger for diesel fuel. The nozzle size is 15/16 inch (24 mm) instead of 13/16 inch (21 mm) for gasoline filler necks. Truck stop diesel nozzles for large over-the-road trucks are usually larger, 1.25 inch or 1.5 inch (32 mm or 38 mm) to allow for faster fueling of large-capacity fuel tanks.

- There are no evaporative emission control devices or a charcoal (carbon) canister. Diesel fuel is not as volatile as gasoline and, therefore, diesel vehicles do not have evaporative emission control devices.

The diesel fuel is usually drawn from the fuel tank by a separate pump, called a **lift pump** and delivers the fuel to the injection pump. Between the fuel tank and the lift pump is a **water-fuel separator**. Water is heavier than diesel fuel and sinks to the bottom of the separator. Part of normal routine maintenance on a vehicle equipped with a diesel engine is to drain the water from the water-fuel separator. A float is often used inside the separator, which is connected to a warning light on the dash that lights if the water reaches a level where it needs to be drained. The water separator is often part of the fuel filter assembly. Both the fuel filter and the water separator are common maintenance items.

**NOTE:** Water can cause corrosive damage and wear to diesel engine parts because it is not a good lubricant. Water cannot be atomized by a diesel fuel injector nozzle and will often "blow out" the nozzle tip.

Many diesel engines also use a **fuel temperature sensor.** The computer uses this information to adjust fuel delivery based on the density of the fuel. ✔ **SEE FIGURE 11–7.**

### INJECTION PUMP

**NEED FOR HIGH-PRESSURE FUEL PUMP** A diesel engine injection pump is used to increase the pressure of the diesel fuel from very low values from the lift pump to the extremely high pressures needed for injection.

- The lift pump is a **low-pressure, high-volume pump.**

- The high-pressure injection pump is a **high-pressure, low-volume pump.**

Injection pumps are usually driven by a gear off the camshaft at the front of the engine. As the injection pump shaft rotates, the diesel fuel is fed from a fill port to a high-pressure chamber. If a distributor-type injection pump is used, the fuel
is forced out of the injection port to the correct injector nozzle through the high-pressure line. \textbf{SEE FIGURE 11–8.}

\textbf{NOTE:} Because of the very tight tolerances in a diesel engine, the smallest amount of dirt can cause excessive damage to the engine and to the fuel-injection system.

\textbf{DISTRIBUTOR INJECTION PUMP} A distributor diesel injection pump is a high-pressure pump assembly with lines leading to each individual injector. The high-pressure lines between the distributor and the injectors must be the exact same length to ensure proper injection timing. The high-pressure fuel causes the injectors to open. Due to the internal friction of the lines, there is a slight delay before fuel pressure opens the injector nozzle. The injection pump itself creates the injection advance needed for engine speeds above idle often by using a stepper motor attached to the advance piston, and the fuel is then discharged into the lines. \textbf{SEE FIGURE 11–9.}
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Heui system
Prin CiPles oF oPeration
Ford 7.3, 6.0, and 6.4 liter (and Navistar) diesels use a system called a hydraulic

electronic unit injection system, or HEUI system. The components used include:
- High-pressure engine oil pump and reservoir
- Pressure regulator for the engine oil
- Passages in the cylinder head for flow of fuel to the injectors

OPERATION The engine oil is pressurized to provide an opening pressure strong enough to overcome the fuel pressure when the solenoid is commanded to open by the PCM. The system functions as follows:
- Fuel is drawn from the tank by the tandem fuel pump, which circulates fuel at low pressure through the fuel filter/water separator/fuel heater bowl and then fuel is directed back to the fuel pump where fuel is pumped at high pressure into the cylinder head fuel galleries.
- The injectors, which are hydraulically actuated by engine oil pressure from the high-pressure oil pump, are then fired by the powertrain control module (PCM). The control system for the fuel injectors is the PCM, and the

Note: The lines expand during an injection event. This is how timing checks are performed. The pulsing of the injector line is picked up by a probe used to detect the injection event similar to a timing light used to detect a spark on a gasoline engine.

High-pressure common rail
Newer diesel engines use a fuel delivery system referred to as a high-pressure common rail (HPCR) design. Diesel fuel under high pressure, over 20,000 PSI (138,000 kPa), is applied to the injectors, which are opened by a solenoid controlled by the computer. Because the injectors are computer controlled, the combustion process can be precisely controlled to provide maximum engine efficiency with the lowest possible noise and exhaust emissions. See Figure 11-10.

Overview of a computer-controlled high-pressure common rail V-8 diesel engine.

See Figure 11-10

Principles of operation Ford 7.3, 6.0, and 6.4 liter (and Navistar) diesels use a system called a hydraulic

Electronic unit injection system, or HEUI system. The components used include:
- High-pressure engine oil pump and reservoir
- Pressure regulator for the engine oil
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- The injectors, which are hydraulically actuated by engine oil pressure from the high-pressure oil pump, are then fired by the powertrain control module (PCM). The control system for the fuel injectors is the PCM, and the
HEUI injectors rely on O-rings to keep fuel and oil from mixing or escaping, causing performance problems or engine damage. HEUI injectors use five O-rings. The three external O-rings should be replaced with updated O-rings if they fail. The two internal O-rings are not replaceable and if these fail, the injector(s) must be replaced. The most common symptoms of injector O-ring trouble include:

- Oil getting in the fuel
- The fuel filter element turning black
- Long cranking times before starting
- Sluggish performance
- Reduction in power
- Increased oil consumption (This often accompanies O-ring problems or any fault that lets fuel in the oil.)

**Change Oil Regularly in a Ford Diesel Engine**

Ford 7.3, 6.0, and 6.4 liter diesel engines pump unfiltered oil from the sump to the high-pressure oil pump and then to the injectors. This means not changing oil regularly can contribute to accumulation of dirt in the engine and will subject the fuel injectors to wear and potential damage as particles suspended in the oil get forced into the injectors.

- **Injector body.** This is the inner part of the nozzle and contains the injector needle valve and spring, and threads into the outer heat shield.
- **Diesel injector needle valve.** This precision machined valve and the tip of the needle seal against the injector body when it is closed. When the valve is open, diesel fuel is sprayed into the combustion chamber. This passage is controlled by a computer-controlled solenoid on diesel engines equipped with computer-controlled injection.
- **Injector pressure chamber.** The pressure chamber is a machined cavity in the injector body around the tip of the injector needle. Injection pump pressure forces fuel into this chamber, forcing the needle valve open.

**DIESEL INJECTOR NOZZLE OPERATION** The electric solenoid attached to the injector nozzle is computer controlled and opens to allow fuel to flow into the injector pressure chamber. **SEE FIGURE 11–12.**

The fuel flows down through a fuel passage in the injector body and into the pressure chamber. The high fuel pressure in the pressure chamber forces the needle valve upward,
GLOW PLUGS

PURPOSE AND FUNCTION  Glow plugs are always used in diesel engines equipped with a precombustion chamber and may be used in direct injection diesel engines to aid starting. A glow plug is a heating element that uses 12 volts from the battery and aids in the starting of a cold engine by providing heat to help the fuel to ignite.  SEE FIGURE 11–14.

As the temperature of the glow plug increases, the resistance of the heating element inside increases, thereby reducing the current in amperes needed by the glow plugs.

OPERATION  Most glow plugs used in newer vehicles are controlled by the Powertrain Control Module, which monitors coolant temperature and intake air temperature. The glow plugs are turned on or pulsed on or off depending on the temperature of the engine. The PCM will also keep the glow plug turned on after the engine starts, to reduce white exhaust smoke (unburned fuel) and to improve idle quality after starting.  SEE FIGURE 11–15.

The “wait to start” lamp (if equipped) will light when the engine and the outside temperatures are low to allow time for the glow plugs to get hot.

Never Allow a Diesel Engine to Run Out of Fuel

If a gasoline-powered vehicle runs out of gasoline, it is an inconvenience and a possible additional expense to get some gasoline. However, if a vehicle equipped with a diesel engine runs out of fuel, it can be a major concern.

Besides adding diesel fuel to the tank, the other problem is getting all of the air out of the pump, lines, and injectors so the engine will operate correctly.

The procedure usually involves cranking the engine long enough to get liquid diesel fuel back into the system, but at the same time keeping cranking time short enough to avoid overheating the starter. Consult service information for the exact service procedure if the diesel engine is run out of fuel.

NOTE: Some diesel engines, such as the General Motors Duramax V-8, are equipped with a priming pump located under the hood on top of the fuel filter. Pushing down and releasing the priming pump with a vent valve open will purge any trapped air from the system. Always follow the vehicle manufacturer’s instructions.
Because a diesel engine is unthrottled, it creates very little vacuum in the intake manifold. Several engine and vehicle components operate using vacuum, such as the exhaust gas recirculation (EGR) valve and the heating and ventilation blend and air doors. Most diesels used in cars and light trucks are equipped with an engine-driven vacuum pump to supply the vacuum for these components.

**HEATED INLET AIR** Some diesel engines, such as the Ram Cummins and the General Motors 6.6 liter Duramax V-8, use an electrical heater wire to warm the intake air to help in cold weather starting and running. **SEE FIGURE 11–16.**

**ENGINE-DRIVEN VACUUM PUMP**
Diesel Fuel Heaters

Diesel fuel heaters help prevent power loss and stalling in cold weather. The heater is placed in the fuel line between the tank and the primary filter. Some fuel heaters are thermostatically controlled, which allows fuel to bypass the heater once it has reached operating temperature.

NOTE: Diesel fuel designed for on-road use should be green and the price includes a road use tax. Red diesel fuel should only be found in off-road or farm equipment and is not taxed.

Accelerator Pedal Position Sensor

Some light-truck diesel engines are equipped with an electronic throttle to control the amount of fuel injected into the engine. Because a diesel engine does not use a throttle in the air intake, the only way to control engine speed is by controlling the amount of fuel being injected into the cylinders. Instead of a mechanical link from the accelerator pedal to the diesel injection pump, a throttle-by-wire system uses an accelerator pedal position (APP) sensor. To ensure safety, it consists of three separate sensors that change in voltage as the accelerator pedal is depressed. ● SEE FIGURE 11–17.

The computer checks for errors by comparing the voltage output of each of the three sensors inside the APP and compares them to what they should be if there are no faults. If an error is detected, the engine and vehicle speed are often reduced.

Turbocharged Diesels

A turbocharger greatly increases engine power by pumping additional compressed air into the combustion chambers. This allows a greater quantity of fuel to be burned in the cylinders resulting in greater power output. In a turbocharger, the turbine wheel spins as exhaust gas flows out of the engine and drives the turbine blades. The turbine spins the compressor wheel at the opposite end of the turbine shaft, pumping air into the intake system. ● SEE FIGURE 11–18.

Air Charge Cooler

The air charge cooler is installed in the air flow between the turbocharger discharge and the inlet air of the engine and is also called an intercooler. It is needed because the air is heated when compressed by the
A variable vane turbocharger is used on many diesel engines for boost control. Boost pressure is controlled independent of engine speed and a wastegate is not needed. The adjustable vanes mount to a unison ring that allows the vanes to move. As the position of the unison ring rotates, the vanes change angle. The vanes are opened to minimize flow at the turbine and exhaust back pressure at low engine speeds. To increase turbine speed, the vanes are closed. The velocity of the exhaust gases increases, as does the speed of the turbine. The unison ring is connected to a cam that is positioned by a rack-and-pinion gear. The turbocharger’s vane position actuator solenoid connects to a hydraulic piston, which moves the rack to rotate the pinion gear and cam. See Figure 11–20.

The turbocharger vane position control solenoid valve is used to advance the unison ring’s relationship to the turbine and thereby articulate the vanes. This solenoid actuates a spool valve that applies oil pressure to either side of a piston. Oil flow has three modes: apply, hold, and release.

- **Apply** moves the vanes toward a closed position.
- **Hold** maintains the vanes in a fixed position.
- **Release** moves the vanes toward the open position.

The turbocharger vane position actuation is controlled by the ECM, which can change turbine boost efficiency independent of engine speed. The ECM provides a control signal to the valve solenoid along with a low-side reference. A pulse-width-modulated signal from the ECM moves the valve to the desired position.

The EGR system recycles some exhaust gas back into the intake stream to cool combustion, which reduces oxides of nitrogen (NOx) emissions. The EGR system includes:

- Plumbing that carries some exhaust gas from the turbocharger exhaust inlet to the intake ports
- EGR control valve
- Stainless steel cooling element used to cool the exhaust gases (See Figure 11–21.)
Particulate matter (PM), also called soot, refers to tiny particles of solid or semisolid material suspended in the atmosphere. This includes particles between 0.1 and 50 microns in diameter. The heavier particles, larger than 50 microns, typically tend to settle out quickly due to gravity. Particulates are generally categorized as follows:

- Total suspended particulate (TSP). Refers to all particles between 0.1 and 50 microns. Up until 1987, the Environmental Protection Agency (EPA) standard for particulates was based on levels of TSP.
- PM10. Refers to particulate matter of 10 microns or less (approximately 1/6 the diameter of a human hair). EPA has a standard for particles based on levels of PM10.
- PM2.5. Refers to particulate matter of 2.5 microns or less (approximately 1/20 the diameter of a human hair), also called “fine” particles. In July 1997, the EPA approved a standard for PM2.5. **SEE FIGURE 11–22.**

### Soot Categories

In general, soot particles produced by diesel combustion fall into the following categories.

**DIESEL PARTICULATE MATTER**

**PARTICULATE MATTER STANDARDS** Particulate matter (PM), also called soot, refers to tiny particles of solid or semisolid material suspended in the atmosphere. This includes particles between 0.1 and 50 microns in diameter. The heavier particles, larger than 50 microns, typically tend to settle out quickly due to gravity. Particulates are generally categorized as follows:

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**SOOT CATEGORIES** In general, soot particles produced by diesel combustion fall into the following categories.

**FREQUENTLY ASKED QUESTION**

**What Is the Big Deal for the Need to Control Very Small Soot Particles?**

For many years soot or particulate matter (PM) was thought to be less of a health concern than exhaust emissions from gasoline engines. It was felt that the soot could simply fall to the ground without causing any noticeable harm to people or the environment. However, it was discovered that the small soot particulates when breathed in are not expelled from the lungs like larger particles but instead get trapped in the deep areas of the lungs where they accumulate.

- **Fine.** Less than 2.5 microns
- **Ultrafine.** Less than 0.1 micron, and make up 80% to 95% of soot

**DIESEL OXIDATION CATALYST**

**PURPOSE AND FUNCTION** Diesel oxidation catalysts (DOC) are used in all light-duty diesel engines, since 2007. They consist of a flow-through honeycomb-style substrate structure that is wash coated with a layer of catalyst materials, similar to those used in a gasoline engine catalytic converter. These materials include the precious metals platinum and palladium, as well as other base metal catalysts.
Diesel exhaust particulate filters (DPFs) are used in all light-duty diesel vehicles, since 2007, to meet the exhaust emissions standards. The heated exhaust gas from the DOC flows into the DPF, which captures diesel exhaust gas particulates (soot) to prevent them from being released into the atmosphere. ● SEE FIGURE 11–24. This is done by forcing the exhaust through a porous cell which has a silicon carbide substrate with honeycomb-cell-type channels that trap the soot. The main difference between the DPF and a typical catalyst filter is that the entrance to every other cell channel in the DPF substrate is blocked at one end. So instead of flowing directly through the channels, the exhaust gas is forced through the porous walls of the blocked channels and exits through the adjacent open-ended channels. This type of filter is also referred to as a “wall-flow” filter.

**OPERATION** Soot particulates in the gas remain trapped on the DPF channel walls where, over time, the trapped particulate matter will begin to clog the filter. The filter must therefore be purged periodically to remove accumulated soot particles. The process of purging soot from the DPF is described as **regeneration**. When the temperature of the exhaust gas is increased, the heat incinerates the soot particles trapped in the filter and is effectively renewed. ● SEE FIGURE 11–25.

**EXHAUST GAS TEMPERATURE SENSORS** The following two exhaust gas temperature sensors are used to help the PCM control the DPF.

- EGT sensor 1 is positioned between the DOC and the DPF where it can measure the temperature of the exhaust gas entering the DPF.
- EGT sensor 2 measures the temperature of the exhaust gas stream immediately after it exits the DPF.

The Powertrain Control Module monitors the signals from the EGT sensors as part of its calibrations to control DPF regeneration. Proper exhaust gas temperatures at the inlet of the DPF are crucial for proper operation and for starting the regeneration process. Too high a temperature at the DPF will cause the DPF substrate to melt or crack. Regeneration will be terminated at temperatures above 1,470°F (800°C). With too low a temperature, self-regeneration will not fully complete the soot-burning process. ● SEE FIGURE 11–26.
CHAPTER 11

The two main regeneration types are as follows:

- **Passive regeneration.** During normal vehicle operation when driving conditions produce sufficient load and exhaust temperatures, passive DPF regeneration may occur. This passive regeneration occurs without input from the PCM or the driver. A passive regeneration may typically occur while the vehicle is being driven at highway speed or towing a trailer.

- **Active regeneration.** Active regeneration is commanded by the PCM when it determines that the DPF requires it to remove excess soot buildup and conditions for filter regeneration have been met. The vehicle needs to be

The DPF differential pressure sensor (DPS) has two pressure sample lines.

- One line is attached before the DPF.
- The other is located after the DPF.

The exact location of the DPS varies by vehicle model type such as medium duty, truck, or van. By measuring the exhaust supply (upstream) pressure from the DOC, and the post DPF (downstream) pressure, the PCM can determine differential pressure, also called “delta” pressure, across the DPF. Data from the DPS is used by the PCM to calibrate for controlling DPF exhaust system operation.

**Diesel Particulate Filter Regeneration**

The primary reason for soot removal is to prevent the buildup of exhaust back pressure. Excessive back pressure increases fuel consumption, reduces power output, and can potentially cause engine damage. Several factors can trigger the diesel PCM to perform regeneration, including:

- Distance since last DPF regeneration
- Fuel used since last DPF regeneration
- Engine run time since last DPF regeneration
- Exhaust differential pressure across the DPF

**DPF Regeneration Process**

A number of engine components are required to function together for the regeneration process to be performed:

1. PCM controls that impact DPF regeneration include late post-injections, engine speed, and adjusting fuel pressure.
2. Adding late post-injection pulses provides the engine with additional fuel to be oxidized in the DOC, which increases exhaust temperatures entering the DPF to 900°F (500°C) or higher. SEE FIGURE 11–27.
3. The intake air valve acts as a restrictor that reduces air entry to the engine, which increases engine operating temperature.
4. The intake air heater may also be activated to warm intake air during regeneration.

**Types of DPF Regeneration**

DPF regeneration can be initiated in a number of ways, depending on the vehicle application and operating circumstances. The two main regeneration types are as follows:

- **Passive regeneration.** During normal vehicle operation when driving conditions produce sufficient load and exhaust temperatures, passive DPF regeneration may occur. This passive regeneration occurs without input from the PCM or the driver. A passive regeneration may typically occur while the vehicle is being driven at highway speed or towing a trailer.

- **Active regeneration.** Active regeneration is commanded by the PCM when it determines that the DPF requires it to remove excess soot buildup and conditions for filter regeneration have been met. The vehicle needs to be

**Frequently Asked Question**

Will the Postinjection Pulses Reduce Fuel Economy?

Maybe. Due to the added fuel-injection pulses and late fuel-injection timing, an increase in fuel consumption may be noticed on the driver information center (DIC) during the regeneration time period. A drop in overall fuel economy should not be noticeable. SEE FIGURE 11–28.
WARNING
Tailpipe outlet exhaust temperature will be greater than 572°F (300°C) during service regeneration. To help prevent personal injury or property damage from fire or burns, keep vehicle exhaust away from any object and people.

FIGURE 11–29 The exhaust is split into two outlets and has slits to help draw outside air in as the exhaust leaves the tailpipe. The end result is cooler exhaust gases exiting the tailpipe.

What Is an Exhaust Air Cooler?
An exhaust air cooler is simply a section of tailpipe that has slits for air to enter. As hot exhaust rushes past the gap, outside air is drawn into the area which reduces the exhaust discharge temperature. The cooler significantly lowers exhaust temperature at the tailpipe from about 800°F (430°C) to approximately 500°F (270°C). ● SEE FIGURE 11–29.

FREQUENTLY ASKED QUESTION

SELECTIVE CATALYTIC REDUCTION

PURPOSE AND FUNCTION Selective catalytic reduction (SCR) is a method used to reduce NOx emissions by injecting urea into the exhaust stream. Instead of using large amounts of exhaust gas recirculation (EGR), the SCR system uses a urea. Urea is used as a nitrogen fertilizer. It is colorless, odorless, and nontoxic. Urea is called diesel exhaust fluid (DEF) in North America and AdBlue in Europe:
● SEE FIGURE 11–30.

The urea is injected into the catalyst where it sets off a chemical reaction which converts nitrogen oxides (NOx) into nitrogen (N2) and water (H2O). Vehicle manufacturers size the onboard urea storage tank so that it needs to be refilled at about each scheduled oil change or every 7,500 miles (12,000 km). A warning light alerts the driver when the urea level needs to be refilled. If the warning light is ignored and the diesel exhaust fluid is not refilled, current EPA regulations require that the operation of the engine be restricted and may not start unless the fluid is refilled. This regulation is designed to prevent the engine from being operated without the fluid, which, if not, would greatly increase exhaust emissions. ● SEE FIGURE 11–31.

ADVANTAGES OF SCR Using urea injection instead of large amounts of EGR results in the following advantages.

- Potential higher engine power output for the same size engine
- Reduced NOx emissions up to 90%
- Reduced HC and CO emissions up to 50%
- Reduced particulate matter (PM) by 50%

Driven at speeds above 30 mph for approximately 20 to 30 minutes to complete a full regeneration. During regeneration, the exhaust gases reach temperatures above 1,000°F (550°C).

ASH LOADING Regeneration will not burn off ash. Only the particulate matter (PM) is burned off during regeneration. Ash is a noncombustible by-product from normal oil consumption. Ash accumulation in the DPF will eventually cause a restriction in the particulate filter. To service an ash-loaded DPF, the DPF will need to be removed from the vehicle and cleaned or replaced. Low ash content engine oil (API CJ-4) is required for vehicles with the DPF system. The CJ-4 rated oil is limited to 1% ash content.
FIGURE 11–31 Urea (diesel exhaust fluid) injection is used to reduce NOx exhaust emissions. It is injected after the diesel oxidation catalyst (DOC) and before the diesel particulate filter (DPF) on this 6.7 liter Ford diesel engine.

DISADVANTAGES OF SCR  Using urea injection instead of large amounts of EGR results in the following disadvantages.

- Onboard storage tank required for the urea
- Difficult to find local sources of urea
- Increased costs to the vehicle owner due to having to refill the urea storage tank

DIESEL EXHAUST SMOKE DIAGNOSIS

Although some exhaust smoke is considered normal operation for many diesel engines, especially older units, the cause of excessive exhaust smoke should be diagnosed and repaired.

BLACK SMOKE  Black exhaust smoke is caused by incomplete combustion because of a lack of air or a fault in the injection system that could cause an excessive amount of fuel in the cylinders. Items that should be checked include the following:

- Injector balance test to locate faulty injectors using a scan tool
- Proper operation of the fuel rail pressure (FRP) sensor
- Restrictions in the intake or turbocharger
- Engine oil usage

WHITE SMOKE  White exhaust smoke occurs most often during cold engine starts because the smoke is usually condensed fuel droplets. White exhaust smoke is also an indication of cylinder misfire on a warm engine. The most common causes of white exhaust smoke include:

- Inoperative glow plugs
- Low engine compression
- Incorrect injector spray pattern
- Coolant leak into the combustion chamber

GRAY OR BLUE SMOKE  Blue exhaust smoke is usually due to oil consumption caused by worn piston rings, scored cylinder walls, or defective valve stem seals. Gray or blue smoke can also be caused by a defective injector(s).

Always start the diagnosis of a diesel engine concern by checking the oil. Higher than normal oil level can indicate that diesel fuel has leaked into the oil. Diesel engines can be diagnosed using a scan tool in most cases, because most of the pressure sensors values can be displayed. Common faults include:

- Hard starting
- No start
- Extended cranking before starting
- Low power

Using a scan tool, check the sensor values in \textbf{CHART 11–2}, to help pin down the source of the problem. Also check the minimum pressures that are required to start the engine if a no-start condition is being diagnosed. \textbf{SEE FIGURE 11–32}.
### DIESEL TROUBLESHOOTING CHART

#### 5.9 DODGE/RAM CUMMINS 2003–2008

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-pressure pump</td>
<td>8–12 PSI</td>
</tr>
<tr>
<td>Pump amperes</td>
<td>4 A</td>
</tr>
<tr>
<td>Pump volume</td>
<td>45 oz. in 30 sec.</td>
</tr>
<tr>
<td>High-pressure pump</td>
<td>5,000–23,000 PSI</td>
</tr>
<tr>
<td>Idle PSI</td>
<td>5,600–5,700 PSI</td>
</tr>
<tr>
<td>Electronic Fuel Control (EFC) maximum fuel pressure</td>
<td>Disconnect EFC to achieve maximum pressure</td>
</tr>
<tr>
<td>Injector volts</td>
<td>90 V</td>
</tr>
<tr>
<td>Injector amperes</td>
<td>20 A</td>
</tr>
<tr>
<td>Glow plug amperes</td>
<td>60–80 A × 2 (120–160 A)</td>
</tr>
<tr>
<td>Minimum PSI to start</td>
<td>5,000 PSI</td>
</tr>
</tbody>
</table>

#### GM DURAMAX 2001–2008

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-pressure pump vacuum</td>
<td>2–10 inch Hg</td>
</tr>
<tr>
<td>Pump amperes</td>
<td>NA</td>
</tr>
<tr>
<td>Pump volume</td>
<td>NA</td>
</tr>
<tr>
<td>High-pressure pump</td>
<td>5,200–5,800 PSI (37–40 MPa)</td>
</tr>
<tr>
<td>Idle PSI</td>
<td>5,000–6,000 PSI (30–40 MPa)</td>
</tr>
<tr>
<td>Fuel Rail Pressure Regulator (FRPR) maximum fuel pressure</td>
<td>Disconnect to achieve maximum pressure</td>
</tr>
<tr>
<td>Injector volts</td>
<td>48 V or 93 V</td>
</tr>
<tr>
<td>Injector amperes</td>
<td>20 A</td>
</tr>
<tr>
<td>Glow plug amperes</td>
<td>160 A</td>
</tr>
<tr>
<td>Minimum to start</td>
<td>1,500 PSI (10 MPa)</td>
</tr>
</tbody>
</table>

#### SPRINTER 2.7 2002–2006

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-pressure pump</td>
<td>6–51 PSI</td>
</tr>
<tr>
<td>High-pressure pump</td>
<td>800–23,000 PSI</td>
</tr>
<tr>
<td>Idle PSI</td>
<td>4,900 PSI</td>
</tr>
<tr>
<td>Fuel Rail Pressure Control (FRPC) maximum fuel pressure</td>
<td>Apply power and ground to FRPC to achieve maximum pressure</td>
</tr>
<tr>
<td>Injector volts</td>
<td>80 V</td>
</tr>
<tr>
<td>Injector amperes</td>
<td>20 A</td>
</tr>
<tr>
<td>Glow plug amperes</td>
<td>17 A each (85–95 A total)</td>
</tr>
<tr>
<td>Minimum to start</td>
<td>3,200 PSI (1–1.2 V to start)</td>
</tr>
</tbody>
</table>

#### 6.0 POWERSTROKE 2003–2008

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-pressure pump</td>
<td>50–60 PSI</td>
</tr>
<tr>
<td>High-pressure pump</td>
<td>500–4,000 PSI</td>
</tr>
<tr>
<td>Idle PSI</td>
<td>500 PSI+</td>
</tr>
<tr>
<td>Injection Pressure Regulator (IPR) maximum fuel pressure</td>
<td>Apply power and ground to IPR</td>
</tr>
<tr>
<td>Injector volts</td>
<td>48 V</td>
</tr>
<tr>
<td>Injector amperes</td>
<td>20 A</td>
</tr>
<tr>
<td>Glow plug amperes</td>
<td>20–25 A each (160–200 A total)</td>
</tr>
<tr>
<td>Minimum to start</td>
<td>500 PSI (0.85 V)</td>
</tr>
</tbody>
</table>

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The values can be obtained by using a scan tool and basic test equipment. Always follow the vehicle manufacturer’s recommended procedures.
GLOW PLUG RESISTANCE BALANCE TEST

Glow plugs increase in resistance as their temperature increases. All glow plugs should have about the same resistance when checked with an ohmmeter. A similar test of the resistance of the glow plugs can be used to detect a weak cylinder. This test is particularly helpful on a diesel engine that is not computer controlled. To test for even cylinder balance using glow plug resistance, perform the following on a warm engine.

1. Unplug, measure, and record the resistance of all glow plugs.
2. With the wires still removed from the glow plugs, start the engine.
3. Allow the engine to run for several minutes to allow the combustion inside the cylinder to warm the glow plugs.
4. Measure the plugs and record the resistance of all glow plugs.
5. The resistance of all glow plugs should be higher than at the beginning of the test. A glow plug that is in a cylinder that is not firing correctly will not increase in resistance as much as the others.
6. Another test is to measure exhaust manifold temperature at each exhaust port using an infrared thermometer or a pyrometer. Misfiring cylinders run cooler than normally firing cylinders.

INJECTOR POP TESTING

A pop tester is a device used for checking a diesel injector nozzle for proper spray pattern. The handle is depressed and pop-off pressure is displayed on the gauge. *SEE FIGURE 11–34.*

The spray pattern should be a hollow cone, but will vary depending on design. The nozzle should also be tested for leakage (dripping of the nozzle) while under pressure. If the spray pattern is not correct, then cleaning, repairing, or replacing the injector nozzle may be necessary.

DIESEL EMISSION TESTING

OPACITY TEST The most common diesel exhaust emission test used in state or local testing programs is called the opacity test. Opacity means the percentage of light that is blocked by the exhaust smoke.

- A 0% opacity means that the exhaust has no visible smoke and does not block light from a beam projected through the exhaust smoke.
Always Use Cardboard to Check for High-Pressure Leaks

If diesel fuel is found on the engine, a high-pressure leak could be present. When checking for such a leak, wear protective clothing including safety glasses, a face shield, gloves, and a long-sleeved shirt. Then use a piece of cardboard to locate the high-pressure leak. When a Duramax diesel is running, the pressure in the common rail and injector tubes can reach over 20,000 PSI. At these pressures, the diesel fuel is atomized and cannot be seen but can penetrate the skin and cause personal injury. A leak will be shown as a dark area on the cardboard. When a leak is found, shut off the engine and find the exact location of the leak without the engine running.

**CAUTION:** Sometimes a leak can actually cut through the cardboard, so use extreme care.

A 100% opacity means that the exhaust is so dark that it completely blocks light from a beam projected through the exhaust smoke.

### TECH TIP

**Do Not Switch Injectors**

In the past, it was common practice to switch diesel fuel injectors from one cylinder to another when diagnosing a dead cylinder problem. However, most high-pressure common rail systems used in new diesel engines utilize precisely calibrated injectors that should not be mixed up during service. Each injector has its own calibration number. [SEE FIGURE 11–35.]

### TECH TIP

**SNAP ACCELERATION TEST**

In a snap acceleration test, the vehicle is held stationary, with wheel chocks in place and brakes released as the engine is rapidly accelerated to high idle, with the

- A 50% opacity means that the exhaust blocks half of the light from a beam projected through the exhaust smoke.
  - SEE CHART 11–3.

### CHART 11–3

An opacity test is sometimes used during a state emission test on diesel engines.

- A 20% opacity
- A 40% opacity
- A 60% opacity
- A 80% opacity
- A 100% opacity

**SNAP ACCELERATION TEST**

In a snap acceleration test, the vehicle is held stationary, with wheel chocks in place and brakes released as the engine is rapidly accelerated to high idle, with the

- A 50% opacity means that the exhaust blocks half of the light from a beam projected through the exhaust smoke.
  - SEE CHART 11–3.

**SNAP ACCELERATION TEST**

In a snap acceleration test, the vehicle is held stationary, with wheel chocks in place and brakes released as the engine is rapidly accelerated to high idle, with the

- A 50% opacity means that the exhaust blocks half of the light from a beam projected through the exhaust smoke.
  - SEE CHART 11–3.
transmission in neutral while smoke emissions are measured. This test is conducted a minimum of six times and the three most consistent measurements are averaged for a final score.

**ROLLING ACCELERATION TEST** Vehicles with a manual transmission are rapidly accelerated in low gear from an idle speed to a maximum governed RPM while the smoke emissions are measured.

**STALL ACCELERATION TEST** Vehicles with automatic transmissions are held in a stationary position with the parking brake and service brakes applied while the transmission is placed in “drive.” The accelerator is depressed and held momentarily while smoke emissions are measured. The standards for diesels vary according to the type of vehicle and other factors, but usually include a 40% opacity or less.

**SUMMARY**

1. A diesel engine uses heat of compression to ignite the diesel fuel when it is injected into the compressed air in the combustion chamber.

2. There are two basic designs of combustion chambers used in diesel engines. Indirect injection (IDI) uses a pre-combustion chamber, whereas direct injection (DI) occurs directly into the combustion chamber.

3. The three phases of diesel combustion include:
   a. Ignition delay
   b. Rapid combustion
   c. Controlled combustion

4. The typical diesel engine fuel system consists of the fuel tank, lift pump, water-fuel separator, and fuel filter.

5. The engine-driven injection pump supplies high-pressure diesel fuel to the injectors.

6. The two most common types of fuel injection used in diesel engines are:
   a. Distributor-type injection pump
   b. Common rail design where all of the injectors are fed from the same fuel supply from a rail under high pressure

7. Injector nozzles are either opened by the high-pressure pulse from the distributor pump or electrically by the computer on a common rail design.

8. Glow plugs are used to help start a cold diesel engine and help prevent excessive white smoke during warm-up.

9. Emissions are controlled on newer diesel engines by using a diesel oxidation catalytic converter, a diesel exhaust particulate filter, exhaust gas recirculation, and a selective catalytic reduction system.

10. Diesel engines can be tested using a scan tool, as well as measuring the glow plug resistance or compression reading, to determine a weak or nonfunctioning cylinder.

**REVIEW QUESTIONS**

1. What is the difference between direct injection and indirect injection?

2. What are the three phases of diesel ignition?

3. What are the two most commonly used types of diesel injection systems?

4. Why are glow plugs kept working after the engine starts?

5. What exhaust after treatment is needed to achieve exhaust emission standards for vehicles 2007 and newer?

6. What are the advantages and disadvantages of SCR?

**CHAPTER QUIZ**

1. How is diesel fuel ignited in a warm diesel engine?
   a. Glow plugs
   b. Heat of compression
   c. Spark plugs
   d. Distributorless ignition system

2. Which type of diesel injection produces less noise?
   a. Indirect injection (IDI)
   b. Common rail
   c. Direct injection
   d. Distributor injection

3. Which diesel injection system requires the use of a glow plug?
   a. Indirect injection (IDI)
   b. High-pressure common rail
   c. Direct injection
   d. Distributor injection
4. The three phases of diesel ignition include ___________.
   a. Glow plug ignition, fast burn, slow burn
   b. Slow burn, fast burn, slow burn
   c. Ignition delay, rapid combustion, controlled combustion
   d. Glow plug ignition, ignition delay, controlled combustion

5. What fuel system component is used in a vehicle equipped with a diesel engine that is seldom used on the same vehicle when it is equipped with a gasoline engine?
   a. Fuel filter
   b. Fuel supply line
   c. Fuel return line
   d. Water-fuel separator

6. The diesel injection pump is usually driven by a ___________.
   a. Gear off the camshaft
   b. Belt off the crankshaft
   c. Shaft drive off the crankshaft
   d. Chain drive off the camshaft

7. Which diesel system supplies high-pressure diesel fuel to all of the injectors all of the time?
   a. Distributor
   b. Inline
   c. High-pressure common rail
   d. Rotary

8. Glow plugs should have high resistance when ___________ and lower resistance when ___________.
   a. Cold/warm
   b. Warm/cold
   c. Wet/dry
   d. Dry/wet

9. Technician A says that glow plugs are used to help start a diesel engine and are shut off as soon as the engine starts. Technician B says that the glow plugs are turned off as soon as a flame is detected in the combustion chamber. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. What part should be removed to test cylinder compression on a diesel engine?
    a. Injector
    b. Intake valve rocker arm and stud
    c. Glow plug
    d. Glow plug or injector