chapter 15

EXHAUST AND AFTERTREATMENT SYSTEMS

LEARNING OBJECTIVES: After studying this chapter, the reader should be able to: • Identify the components of the exhaust and aftertreatment systems. • Describe the function of each aftertreatment system. • Explain the differences between active and passive regeneration. • Explain how temperature sensors are used to monitor component operation. • Describe the function of the diesel exhaust fluid (DEF) in the selective catalyst reduction (SCR) system.

KEY TERMS: • Active regeneration 171 • Ammonia (NH_3) 169 • Exhaust backpressure regulator (EBPR) 167 • Carbon dioxide (CO_2) 166 • Carbon monoxide (CO) 166 • Diesel exhaust fluid (DEF) 169 • Diesel oxidation catalyst (DOC) 168 • Diesel Particulate Filter (DPF) 170 • Differential pressure sensor 172 • Exhaust downpipe 167 • Hydrocarbons (HC) 165 • NO_x adsorber catalyst 168 • NO_x sensor 173 • Oxides of nitrogen (NO_x) 166 • Oxygen (O_2) 166 • Oxygen sensor 173 • Particulate matter (PM) 166 • Passive regeneration 171 • Reductant dosing module 169 • Selective catalyst reduction (SCR) 169 • Soot 166 • Temperature sensor 172

EXHAUST CHEMISTRY

EMISSION STANDARDS Tier II diesel emission standards were introduced in 2007 and were phased in until 2010. ● **SEE FIGURE 15–1**.

The changes in standards resulted in a requirement to reduce particulate matter (PM) and oxides of nitrogen (NO_x) emissions by 90%. Changes to fuel control strategies helped to partially achieve these targets. To comply with federally mandated emission standards, the exhaust system was redesigned to include aftertreatment systems. These systems work with other systems on the vehicle to help reduce the level of tailpipe emissions.

TAILPIPE EMISSIONS The tailpipe emissions include:

- **Hydrocarbons (HC)** – Hydrocarbons (HC) are unburned diesel fuel and are measured in parts per million (ppm). A correctly operating engine should burn (oxidize) almost all

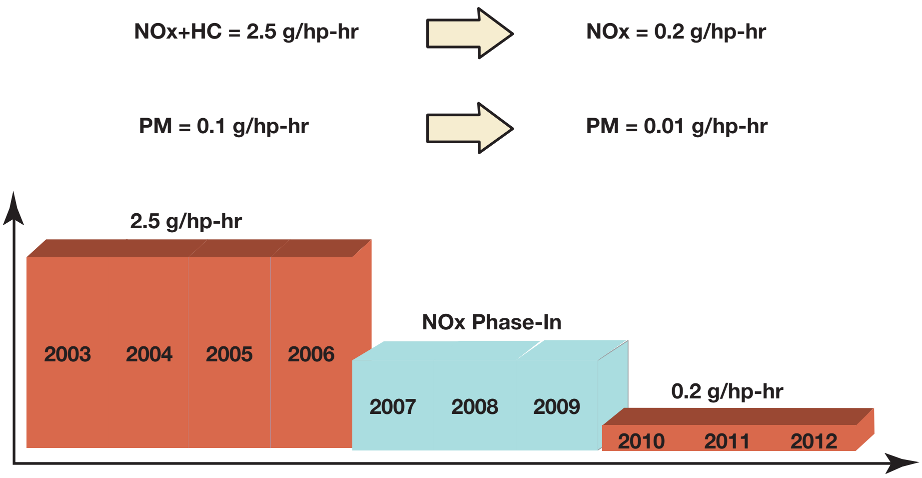

FIGURE 15–1 The emission chart shows the mandated reductions in tailpipe emissions, how they have driven the changes in the way diesel engines operate, and how the exhaust aftertreatment is configured.

the diesel fuel; therefore, very little unburned diesel fuel should be present in the exhaust. Acceptable levels of HC are 50 ppm or less. High levels of HC could be due to excessive oil consumption or the over fueling of the cylinder.

- **Carbon monoxide (CO)** – Carbon monoxide (CO) is a result of partially burned diesel fuel. Carbon monoxide (CO) is unstable and will easily combine with any oxygen (O_2) to form stable carbon dioxide (CO_2). The fact that CO combines with oxygen (O_2) is the reason that CO is a poisonous gas (in the lungs, it combines with oxygen (O_2) to form CO_2 and deprives the brain of oxygen (O_2). CO levels of a properly operating engine should be less than 0.5%.
- **Oxides of nitrogen (NO_x)** – An oxide of nitrogen (NO) is a colorless, tasteless, and odorless gas when it leaves the engine, but as soon as it reaches the atmosphere and mixes with more oxygen, nitrogen oxides (NO_2) are formed. NO_2 is reddish-brown and has an acid and pungent smell. NO and NO_2 are grouped together and referred to as NO_x, where 'x' represents any number of oxygen (O_2) atoms. NO_x, the symbol used to represent all oxides of nitrogen (NO_x). The oxides of nitrogen are a result of high combustion temperatures and pressures.
- **Particulate matter (PM)** – 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, 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 15–2.**
- **Oxygen (O_2)** – There is about 21% oxygen (O_2 in the atmosphere), and most of this oxygen (O_2) should be "used up" during the combustion process to oxidize all the hydrogen and carbon (hydrocarbons) in the diesel fuel. Levels of O_2 should be very low (about 0.5%). High levels of O_2, especially at idle, could be due to an exhaust system leak.
- **Carbon Dioxide (CO_2)** – Carbon dioxide (CO_2) is the result of oxygen (O_2) in the engine, combining with the carbon of the diesel fuel. An acceptable level of CO_2 is between 12% and 15%. A high reading indicates an efficiently operating engine. If the CO_2 level is low, the mixture may be either too rich or too lean.

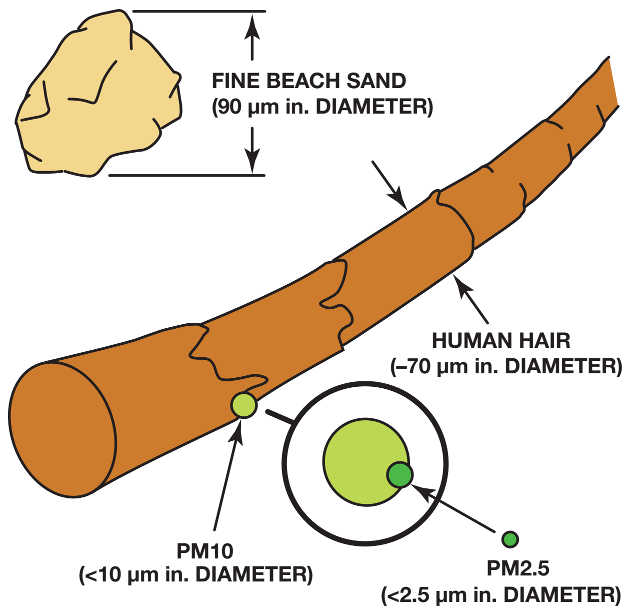

FIGURE 15–2 Relative size of particulate matter to a human hair.

VEHICLE EMISSIONS CERTIFICATION The vehicle emission certification will vary depending on the model year and the gross vehicle weight (GVWR). To determine how the vehicle is certified, the vehicles emission certification label, typically found under the hood, should be referenced. It will list the components the vehicle was equipped with at the time of emission certification. ● **SEE FIGURE 15–3.**

EXHAUST SYSTEM FUNCTION The exhaust and aftertreatment system on the modern light-duty diesel vehicle serve a number of functions. The exhaust system safely directs the engine exhaust gases away from the passenger compartment and it helps to reduce the level of the exhaust noise. The system design is larger in diameter than a conventional gasoline engine to allow the engine to properly breath, and to ensure the exhaust system backpressure is not excessive. Under boost conditions, a large volume of air is moved through the engine. To comply with federally mandated

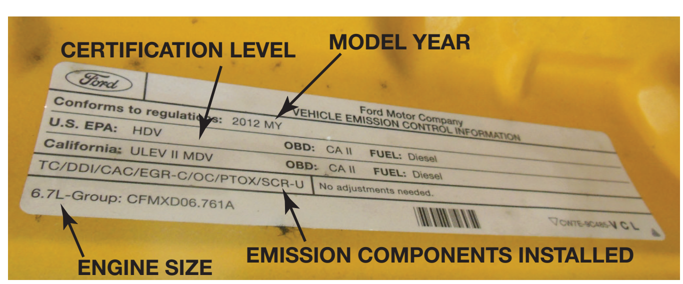

FIGURE 15–3 The emissions certification label identifies how the vehicle is certified.

WARNING

The exhaust system components and the exhaust air stream can be hot enough to cause damage or personal injury. Do not park or operate the vehicle in areas where the exhaust might come in contact with anything that can burn. Use extreme caution when working around these components.

Tier II diesel emission standards, the aftertreatment system consists of the following:

- Diesel oxidation catalyst (DOC)
- Particulate filters
- NO_x catalysts

The components in the aftertreatment system and their location will vary with the model year of the vehicle and the gross vehicle weight (GVW).

EXHAUST SYSTEM COMPONENTS

EXHAUST DOWNPIPE

The **exhaust downpipe** is a critical part of the exhaust system and can be seen coming off the turbocharger. ● **SEE FIGURE 15–4**.

The downpipe is a double-walled construction to help retain heat for the aftertreatment system. Its diameter, length, and construction materials are part of the emission certification and should not be altered or modified.

EXHAUST BACKPRESSURE REGULATORS (EBPR)

Modern diesel engines are slow to warm up under low loads due to the increased efficiency of the combustion process.

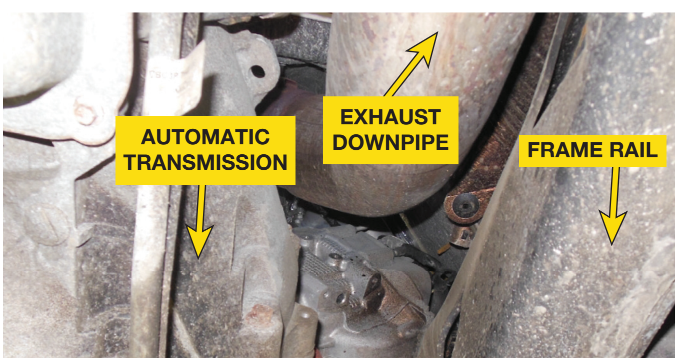

FIGURE 15–4 The exhaust downpipe is constructed to retain heat to help the aftertreatment work as designed.

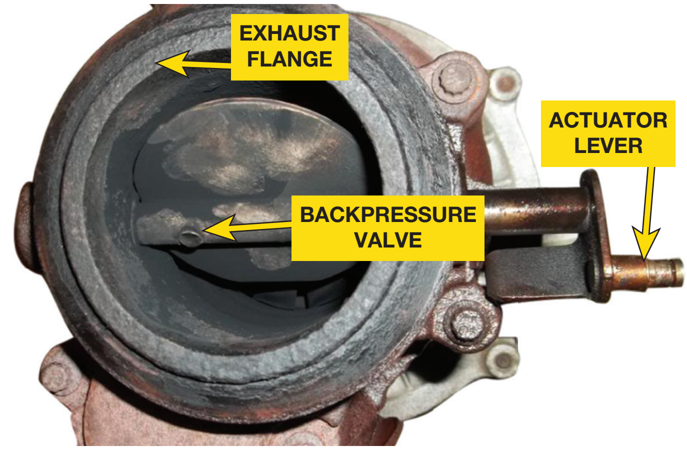

FIGURE 15–5 The exhaust backpressure regulator (EBPR) allows the engine to warm to operating conditions more quickly.

As a result, manufacturers may have a difficult time achieving the desired tailpipe emissions during the warm-up cycle. The addition of an **exhaust backpressure regulator (EBPR)** to the exhaust system will allow the engine to warm-up to operating conditions more quickly. ● **SEE FIGURE 15–5**.

The exhaust backpressure regulator (EBPR) is PCM controlled. By monitoring engine temperatures, the PCM is able to control the valve to reach and maintain the desired operating temperature.

EXHAUST TAILPIPE

The tailpipe on a modern diesel engine is unique when compared to a vehicle equipped with a gasoline engine. The design is a critical part of helping the aftertreatment work as designed. ● **SEE FIGURE 15–6**.

The tailpipe should be equipped with heat guards to prevent burns for anyone who would make accidental contact. The construction of the tailpipe is typically a double-wall design. This allows for cooling of the heat that is generated during the regeneration process.

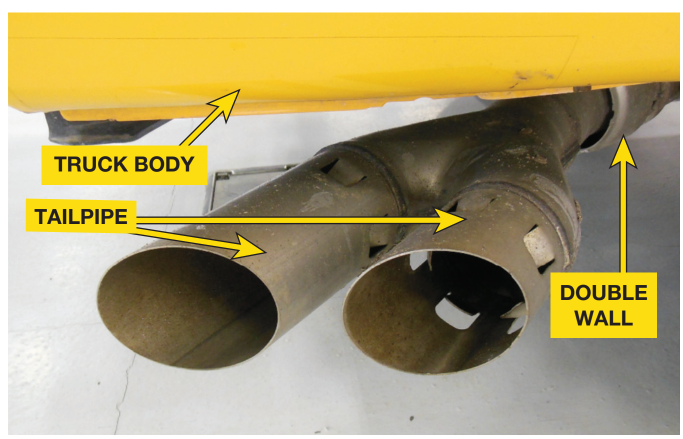

FIGURE 15–6 The design of the tailpipe allows for the cooling of the exhaust during a regeneration event.

DIESEL OXIDATION CATALYST (DOC)

PURPOSE AND FUNCTION On most modern diesel engines, the **diesel oxidation catalyst (DOC)** is the first major component in the exhaust aftertreatment system after the exhaust downpipe. It is packaged in a stainless steel housing. In many cases, it is packaged in the same housing as the diesel particulate filter (DPF). The diesel oxidation catalyst (DOC) helps to reduce the hydrocarbons (HC) and carbon monoxide (CO) created during the combustion process. ● **SEE FIGURE 15–7**.

It also helps to reduce the level of particulate matter (PM) and convert nitrogen monoxide (NO) to nitrogen dioxide (NO_2). The heat created within the catalyst during the oxidation process is used by other components in the aftertreatment system.

PARTS AND OPERATION The DOC is a flow-through device with ceramic honeycomb-like substrate surfaces coated with platinum, palladium, and other semi-precious metals, similar to a catalytic converter on a vehicle equipped with a gasoline engine. During the oxidation process, the hydrocarbons (HC) are combined with the oxygen (O_2), which results in carbon dioxide (CO_2) and water. The carbon monoxide (CO) combines with the oxygen (O_2) to also create carbon dioxide (CO_2) and water. The nitrogen monoxide reacts with the oxygen (O_2) to create nitrogen dioxide. The heat created during these processes burns some of the unburned or partially burned diesel fuel, resulting in a decrease in the level of particulate matter.

NO_X ADSORBER CATALYST

PURPOSE AND FUNCTION The **NO_x adsorber catalyst** is a maintenance-free strategy for removing NO_x emissions in a low-temperature, oxygen-rich environment. This strategy is primarily used on smaller diesel engines where the exhaust volume is low. The NO_x emissions are temporarily held by the catalyst, and then reduced into the natural elements of nitrogen and oxygen (O_2) when the exhaust stream is oxygen (O_2) depleted. ● **SEE FIGURE 15–8**.

PARTS AND OPERATION The substrate in a NO_x adsorber catalyst is covered with a material that is designed to hold the NO_x emissions that primarily occur during lean operating conditions. During rich or oxygen (O_2) depleted operating conditions, the NO_x emissions are oxidized into the natural elements of nitrogen and oxygen (O_2), The system operation is monitored by either oxygen (O_2) sensors or NO_x sensors. Temperature sensors may also be used to determine if the oxidation process is occurring.

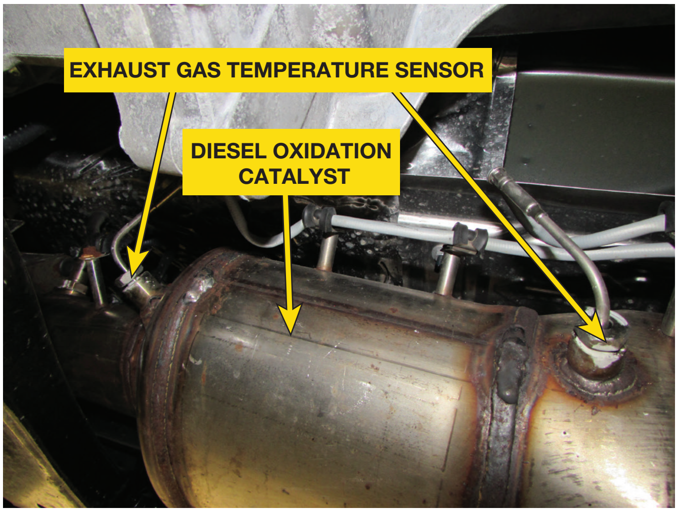

FIGURE 15–7 The diesel oxidation catalyst (DOC) reduces hydrocarbons (HC) and carbon monoxide (CO) through oxidation. The heat generated from the process is used to reduce particulate matter.

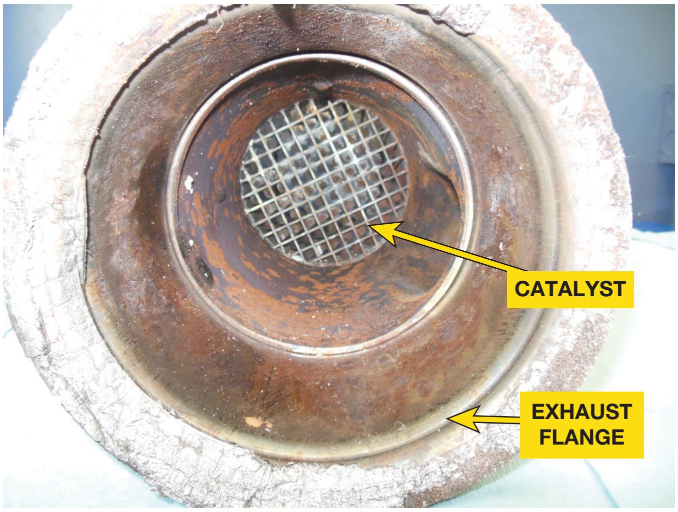

FIGURE 15–8 The NO_x adsorber catalyst holds NO_x emissions during lean conditions and oxidizes them when the operating conditions are rich.

SELECTIVE CATALYST REDUCTION (SCR)

PURPOSE AND FUNCTION The **selective catalyst reduction (SCR)** system is designed to reduce the level of oxides of nitrogen (NO_x) in the exhaust stream. The SCR catalyst may be before or after the diesel particulate filter (DPF), depending on the emissions certification of the vehicle. ● **SEE FIGURE 15–9**.

The ceramic substrate in the catalyst is covered by a wash-coat of copper and iron. Near the inlet of the SCR catalyst is the **reductant dosing module**. This module includes the injection nozzle, the diffuser, and the mixer. Some vehicles use a two-stage catalyst. Together these components atomize the diesel exhaust fluid (DEF) and disperse it evenly onto the substrate.

PARTS AND OPERATION As the diesel exhaust fluid (DEF) heats up, it separates into carbon dioxide (CO_2) and **ammonia (NH_3)**. When the ammonia (NH_3) reacts with the oxides of nitrogen (NO_x), a reduction reaction takes place and the NO_x is converted to nitrogen dioxide and water. The operation of the SCR catalyst is monitored by a NO_x sensor.

FIGURE 15–10 Diesel exhaust fluid (DEF) is available in consumer-friendly containers or in bulk.

DIESEL EXHAUST FLUID

PURPOSE AND FUNCTION **Diesel exhaust fluid (DEF)** is a mixture of 32.5% laboratory grade urea and 67.5% deionized water. ● **SEE FIGURE 15–10**.

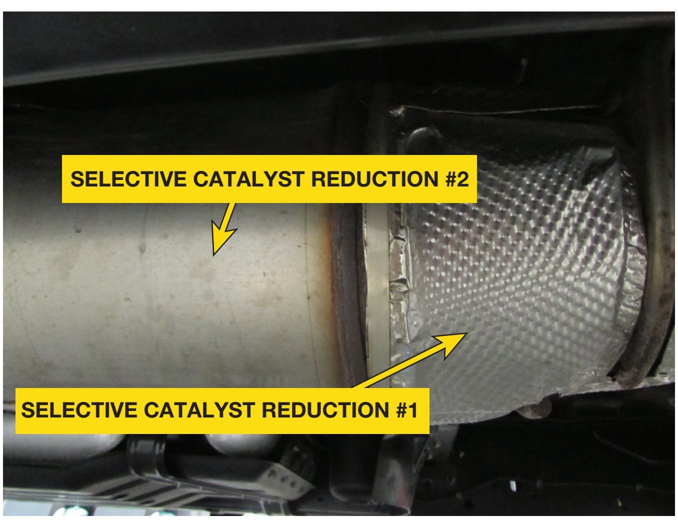

FIGURE 15–9 The SCR catalyst reduces the level of NO_x emissions when the diesel exhaust fluid (DEF) is injected onto its substrate.

Diesel exhaust fluid (DEF) is called AdBlue in Europe. It is important to note that the water in the DEF is not distilled. Deionized water is deeply demineralized, distilled water is not. Urea is synthetic ammonia (NH_3) and carbon dioxide (CO_2) combined under high heat to create a liquid. DEF is nontoxic and is not harmful to handle. It is injected into the exhaust stream upstream of the SCR catalyst. Once inside the catalyst, the heat causes the DEF to decompose into ammonia (NH_3) and carbon dioxide.

To ensure the DEF performs as designed, a refractometer can be used to measure its density. ● **SEE FIGURE 15–11**.

The American Petroleum Institute has established standards for DEF that are used in SCR catalysts. A sample that fails to meet the standard may be contaminated or diluted.

PARTS AND OPERATION The diesel exhaust fluid (DEF) is stored in a reservoir until it is needed. The reservoir is equipped with a pump and a heater. The pump is used to transfer the fluid from the reservoir to the dosing module. Diesel exhaust fluid (DEF) will freeze at about 12°F (-11°C). The concentration of urea and water ensures that both elements will freeze at the same temperature. The heater element in the reservoir is designed to thaw the diesel exhaust fluid (DEF) before it is injected. The quality of the diesel exhaust fluid (DEF) is critical for proper catalyst operation.

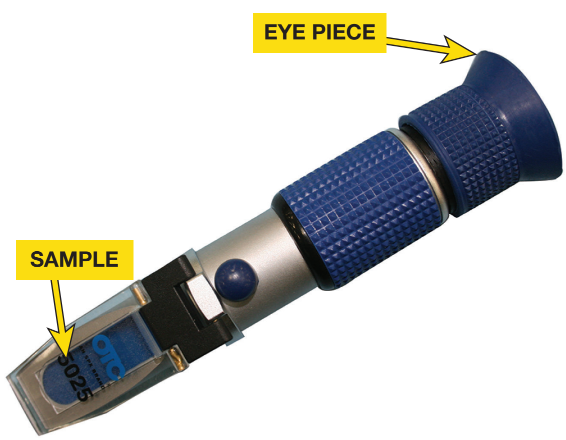

FIGURE 15–11 The refractometer is used to measure the quality of the diesel exhaust fluid (DEF).

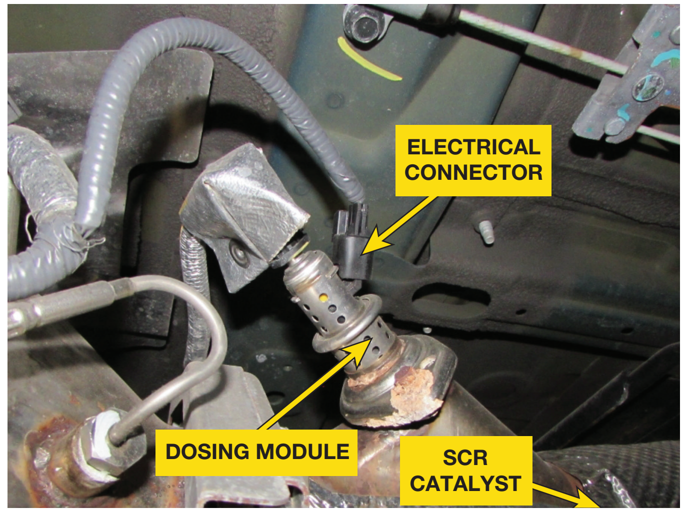

FIGURE 15–12 The reductant dosing module contains the DEF injector, diffuser, and mixer.

REDUCTANT DOSING MODULE

PURPOSE AND FUNCTION As required, the reductant dosing module is designed to inject diesel exhaust fluid (DEF) to reduce the NO_x emissions. This module includes the injection nozzle, the diffuser, and the mixer. Together these components atomize the diesel exhaust fluid (DEF) and disperse it evenly onto the substrate. ● **SEE FIGURE 15–12**.

The vehicle operator has a responsibility to keep the system full of quality DEF. Most vehicles will consume the DEF at a rate of 1% to 4% of fuel consumption, depending on driving conditions. The system is designed to warn the driver when the system fluid level gets low.

PARTS AND OPERATION The reductant dosing module is monitored to ensure that both adequate quantity and adequate quality of diesel exhaust fluid (DEF) is injected into the SCR catalyst. The system is monitored using a NO_x sensor, both upstream and downstream of the catalyst.

DIESEL PARTICULATE FILTER (DPF)

PURPOSE AND FUNCTION The **diesel particulate filter (DPF)** is located in a stainless-steel housing near the diesel oxidation catalyst (DOC) and is responsible for making the exhaust virtually smokeless. The DPF is a wall flow ceramic monolith where alternating channels are plugged. ● **SEE FIGURE 15–13**.

This forces the gasses through the porous walls and holds PM too large to pass through. The DPF filters and stores the particulate matter (PM) that is generated through incomplete combustion. As the particulate matter (PM) gathers in the filter assembly, it begins to restrict the exhaust flow. When the conditions warrant, the particulate matter (PM) is oxidized into CO_2 by increasing the temperature of the filter assembly to at least 600°F (315°C) in a process referred to as regeneration. The result of this process is ash. The ash will remain in the filter until it is cleaned or replaced, depending on service requirements.

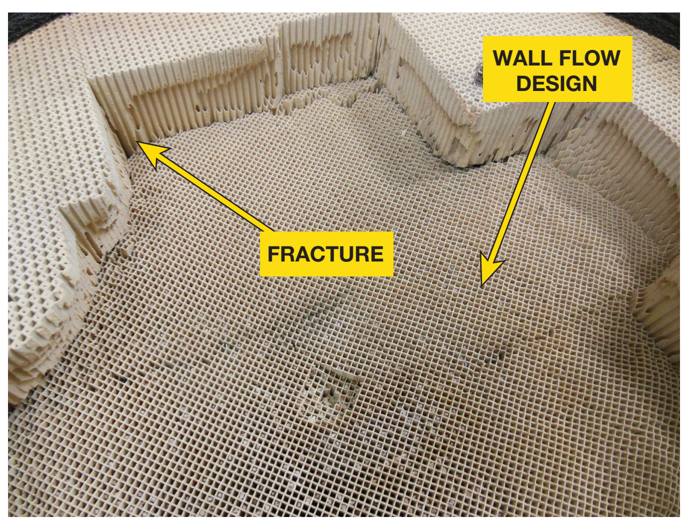

FIGURE 15–13 The DPF monolith is responsible for capturing the particulate matter and holding it until a regeneration event occurs. The DPF pictured failed due to an internal fracture.

FIGURE 15–14 The DPF warning lamp is used to warn the driver the vehicle needs to be driven in a manner that a regeneration event can occur.

PARTS AND OPERATION The diesel particulate filter is designed to trap and hold particulate matter that would otherwise contribute to unwanted tailpipe emissions and smoke. For a regeneration event to occur, specific operating conditions have to be met. The PCM will raise the temperature of the particulate filter and oxidize the particulate matter, leaving only ash residue in the assembly. Most vehicles are designed to hold 150,000 to 200,000 miles of generated ash before service is needed.

If the enabling conditions for a regeneration event are not met through the course of normal driving, a restriction in the exhaust will occur. When a restriction occurs, the PCM is designed to alert the driver. A warning light or message is illuminated on the instrument panel. ● **SEE FIGURE 15–14**.

The driver would then need to operate the vehicle under specific driving conditions, allowing a regeneration event to occur. Failure to head these warning will result in a decrease in performance of the vehicle, the illumination of the MIL, and the recording of a hard fault.

REGENERATION EVENT Regeneration events occur automatically throughout the course of normal driving when the particulate filter becomes restricted. ● **SEE FIGURE 15–15**.

The heat needed for the regeneration event may occur passively or actively. A **passive regeneration** event normally occurs. An **active regeneration** event will only occur if a passive regeneration event cannot reduce the level of particulate in the filter. For diagnostic purposes, some vehicles have a manual regeneration option available for the service technician.

- **Passive Regeneration.** During a passive regeneration event, the engine load is sufficient enough to create the exhaust temperatures needed to eliminate the particulate matter.

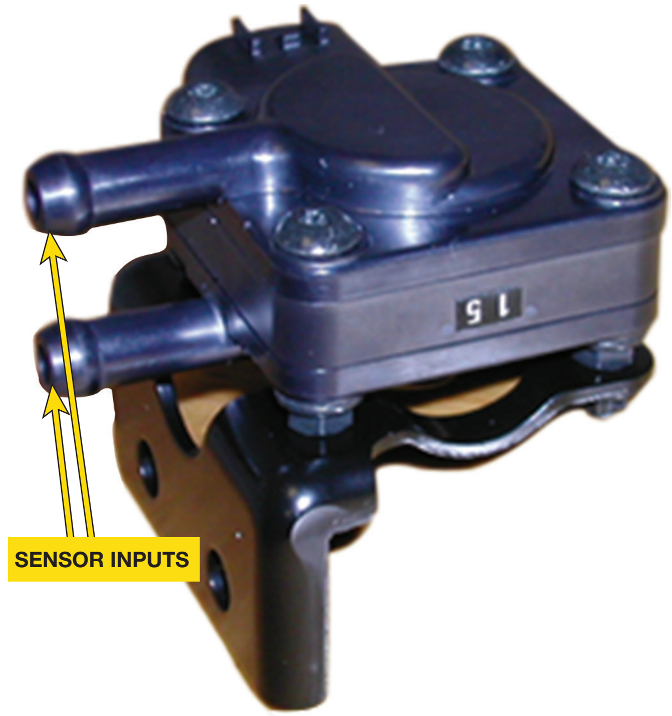

FIGURE 15–15 The feedback from the differential pressure sensor is used by the powertrain control module to determine when a regeneration event is needed.

- **Active Regeneration.** During an active regeneration event, heat is created by adding fuel to the exhaust stream. This fuel can be added either through a post-injection shot at the cylinder or through a dosing valve in the exhaust. The temperature of the diesel particulate filter (DPF) is hotter during an active regeneration event than a passive event.
- **Manual Regeneration.** A manual regeneration event is triggered by the service technician. The system is activated using a scan tool while the vehicle is in a service facility. During the process, the exhaust system will get much hotter than normal. Specific procedures must be followed to ensure there is no damage to the vehicle or harm to the service technician.

DIFFERENTIAL PRESSURE SENSOR

PURPOSE AND FUNCTION A **differential pressure sensor** is used to determine if a restriction exists in the DPF, indicating a need for service or replacement. The sensor compares the pressure at the inlet and outlet of the DPF, and uses that data to determine if a regeneration event is needed.

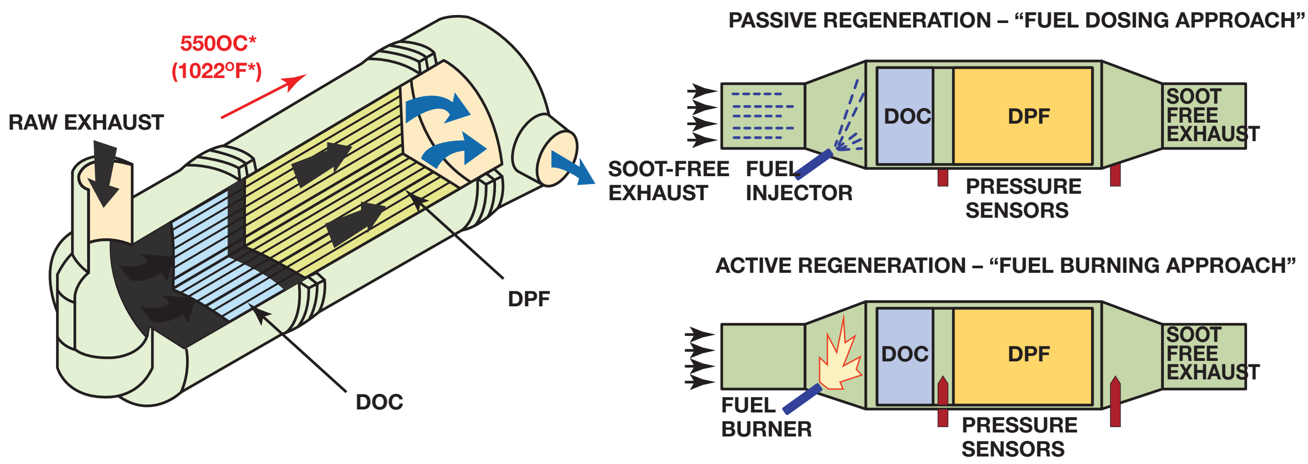

FIGURE 15–16 The sequence of drawings shows the steps of a regeneration event.

The sensor is mounted near the DPF and is connected to it with long metal tubes. ● **SEE FIGURE 15–16**.

These tubes tend to reduce the temperature of the exhaust gases being measured and prolong the life of the sensor.

PARTS AND OPERATION The operation of the sensor is similar to systems used to measure exhaust gas recirculation (EGR) pressures on some gasoline engines. The differential pressure sensor monitors the inlet and outlet pressure during the regeneration event to determine when the restriction no longer exists. During the process, the particulate matter is oxidized leaving only ash in the filter assembly.

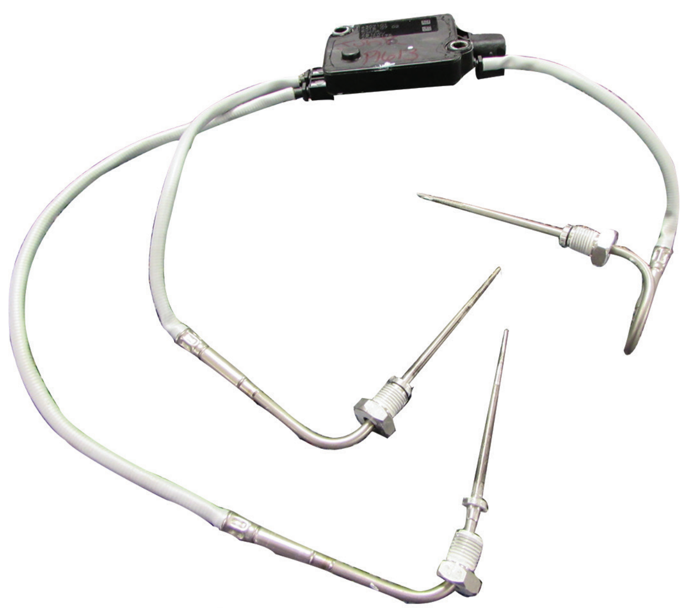

FIGURE 15–17 The temperature sensors are used by the powertrain control module to monitor the function of various components in the aftertreatment system.

TEMPERATURE SENSORS

PURPOSE AND FUNCTION The exhaust aftertreatment system uses multiple **temperature sensors** to monitor the function of components within the system. Some manufacturers refer to these sensors as exhaust gas temperature sensors. They can be mounted in the system in various locations, depending on how the vehicle is certified. ● **SEE FIGURE 15–17**.

The sensors are typically found at the inlet and outlet of a diesel particulate filter and the outlet of a diesel oxidation catalyst. Sometimes the functionally of a single sensor may be used to help monitor multiple systems in the aftertreatment system.

PARTS AND OPERATION The temperature sensor may be used to verify a component is operating as designed. For example, the normal operation of a diesel oxidation catalyst (DOC) will generate heat. The PCM can monitor the temperature at the outlet of the DOC under specific operating conditions, and determine if it is functioning as designed. This is a critical input when meeting the OBDII monitoring requirements. The temperature sensors can also be used to control the operation of a system. A DPF needs to be at a specific temperature during the regeneration process to effectively reduce the level of particulate matter. Using the input from the temperature sensors, the PCM is able to change fuel delivery strategies to bring the DPF to the desired temperature for the duration of the regeneration event. By closely monitoring the temperature, the PCM is able to ensure the DPF does not melt or crack due to high temperature conditions.

NO_x SENSORS

PURPOSE AND FUNCTION The **NO_x sensors** are part of a smart module and are serviced together. It is used to measure the level of NO_x emissions in the aftertreatment system. The NO_x sensor may also be used to determine if the DEF being delivered to the exhaust is of adequate volume and quantity. Depending on how the system is configured, the level of O_2 in the exhaust stream may be inferred based on preprogramed data in the PCM of expected volumes of exhaust gases. The operation of a NO_x sensor is similar to the operation of a wide-band oxygen sensor used on a gasoline engine. The sensor uses a sample chamber and a measurement chamber. The level of NO_x is determined by monitoring the pumping current of the sensor as the gases are moved from the sample chamber through a diffusion barrier into the measurement chamber. The sensor is installed in the aftertreatment system downstream of the SCR catalyst or the DPF. ● **SEE FIGURE 15–18**.

The smart module is a stand-alone module and is designed to operate on the high-speed "CAN bus" to communicate with the PCM. The module not only monitors the exhaust airstream, but it also performs sensor diagnostics.

PARTS AND OPERATION The smart module is able to monitor itself for internal malfunctions and is capable of setting hard codes related to these failures. These failures are corrected by replacing the smart module and sensor as a unit. The module also monitors the circuit continuity of the sensor, as well as the validity of the signal that it is generating.

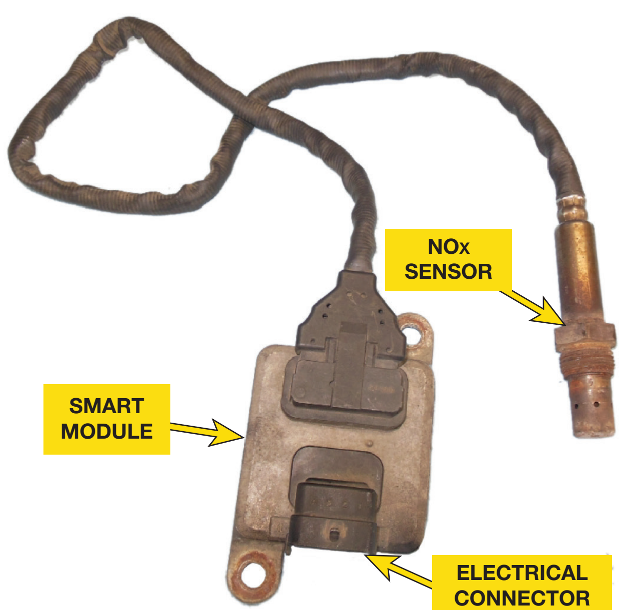

FIGURE 15–18 The NO_x sensor is used to measure the NO_x emissions in the aftertreatment system.

OXYGEN SENSORS

PURPOSE AND FUNCTION Newer diesel vehicles use a wide-band **oxygen sensor** that is capable of accurately monitoring the oxygen (O_2) level in the exhaust stream throughout its broad operating range. ● **SEE FIGURE 15–19**.

The design of the sensor is similar to the modern gasoline engine. A wide-band oxygen sensor is capable of supplying air–fuel ratio information to the PCM over a much broader range. The use of a wide-band oxygen sensor, compared with a conventional zirconia oxygen sensor, differs as follows:

1. Able to detect exhaust air–fuel ratio from as rich as 10:1 and as lean as 23:1 in some cases.
2. Cold-start activity within as little as 10 seconds.
3. Operates at a hotter temperature than a conventional oxygen sensor.

PURPOSE AND FUNCTION Unlike a gasoline engine, the diesel oxygen sensor is not being used to adjust fuel delivery, but rather to control and monitor the EGR system. The PCM will monitor the level of oxygen in the exhaust stream during the EGR process. By comparing the data during the event to expected results, the PCM can control the EGR valve at the desired level of operation and it can monitor performance against fault setting criteria.

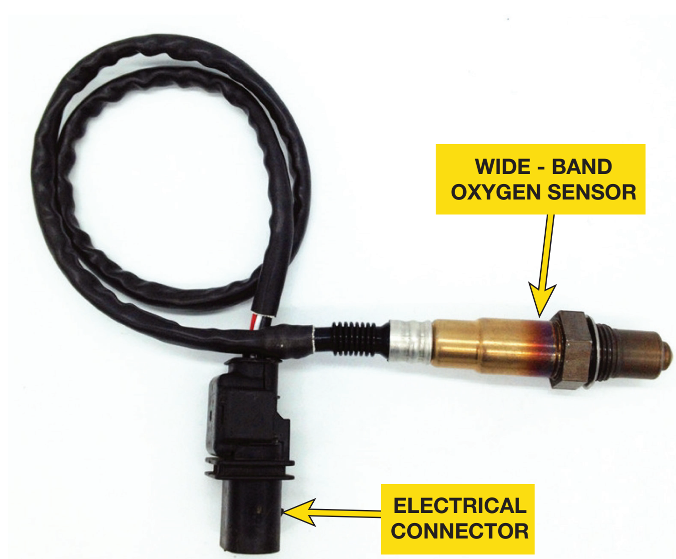

FIGURE 15–19 The oxygen sensor is used to monitor the operation of the EGR system.

SUMMARY

1. Tier II diesel emission standards were introduced in 2007 and were phased in until 2010.
2. The tailpipe emissions include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM), oxygen (O2), and carbon dioxide (CO_2).
3. To comply with federally mandated Tier II diesel emission standards, the aftertreatment system consists of the following:
   - Diesel oxidation catalyst (DOC)
   - Particulate filters
   - NO_x catalysts
4. On most modern diesel engines, the diesel oxidation catalyst (DOC) is the first major component in the exhaust aftertreatment system after the exhaust downpipe.
5. The NO_x adsorber catalyst is a maintenance-free strategy for removing NO_x emissions in a low-temperature, oxygen-rich environment.
6. The selective catalyst reduction (SCR) system is designed to reduce the level of oxides of nitrogen (NO_x) in the exhaust stream.
7. The diesel particulate filter (DPF) is located in a stainless-steel housing near the diesel oxidation catalyst (DOC). It is responsible for making the exhaust virtually smokeless.
8. Diesel exhaust fluid (DEF) is a mixture of 32.5% laboratory grade urea and 67.5% deionized water.
9. Regeneration events occur automatically throughout the course of normal driving when the particulate filter becomes restricted.
10. A differential pressure sensor is used to determine if a restriction exists in the DPF, indicating a need for service or replacement.
11. The exhaust aftertreatment system uses multiple temperature sensors to monitor the function of components within the system. Some manufacturers refer to these sensors as exhaust gas temperature sensors.
12. Newer diesel vehicles use a wide-band oxygen sensor that is capable of accurately monitoring the oxygen level in the exhaust stream throughout its broad operating range.

REVIEW QUESTIONS

1. How does the PCM use the pressure differential sensor to determine if the diesel particulate filter has a restriction?
2. What is the difference between a passive and an active regeneration event?
3. How does a temperature sensor verify the operation of a diesel oxidation catalyst?
4. What is the role of an O_2 sensor (if equipped) in the exhaust aftertreatment system?
5. What happens if the customer fails to maintain the diesel exhaust fluid (DEF) at a minimum level?

CHAPTER QUIZ

1. The implementation of Tier II diesel emissions requirements in 2007 required the reduction of which two tailpipe emissions?
   a. CO and HC
   b. CO and NO_x
   c. PM and NO_x
   d. PM and HC
2. Two technicians are discussing wide-band oxygen sensors on a newer diesel engine. Technician A says they are used to adjust the air-fuel ratio. Technician B says they are used to verify the operation of the EGR system. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technician A and Technician B
   d. Neither Technician A nor Technician B
3. Diesel oxidation catalysts (DOC) are being discussed. Technician A says they are used to reduce the level of hydrocarbons (HC) in the exhaust stream. Technician B says they are used to reduce the level of carbon monoxide (CO) in the exhaust stream. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technician A and Technician B
   d. Neither Technician A nor Technician B
4. The NO_x sensor downstream of the selective catalyst reduction (SCR) system fails to a minimum change in NO_x in the exhaust stream. What could be the cause?
   a. The selective catalyst reduction (SCR) has failed.
   b. The diesel exhaust fluid is of poor quality.
   c. Both A and B
   d. Neither A nor B
5. Diesel exhaust fluid (DEF) is being discussed. Technician A says it includes distilled water. Technician B says it contains 32.5% urea. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technician A and Technician B
   d. Neither Technician A nor Technician B

6. A wide-band oxygen sensor operation differs from a conventional oxygen sensor because __________.
   a. It is able to a monitor a broader air-fuel ratio.
   b. It operates at a hotter temperature.
   c. It becomes operational faster on a cold start.
   d. All of the above
7. The operation of a particulate filter is being discussed. Technician A says that it is designed to reduce NO_x emissions. Technician B says that the filter is designed to trap particulate matter (PM). Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technician A and Technician B
   d. Neither Technician A nor B
8. The operation of a NO_x adsorber catalyst is being discussed. Technician A says that the catalyst will not function properly unless the proper quality and quantity of diesel exhaust fluid is maintained. Technician B says the catalyst oxidizes the NO_x emissions during lean operating conditions. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technician A and Technician B
   d. Neither Technician A nor Technician B
9. Temperature sensors are used to monitor the operation of the __________.
   a. diesel particulate filter and DOC
   b. NO_x adsorber catalyst
   c. SCR catalyst
   d. Both a and b
10. During an active regeneration event:
   a. The temperature of the DPF will be higher than during a passive regeneration event
   b. Will only occur if a passive regeneration event is ineffective
   c. Additional fuel will be added to the DPF
   d. All of the above