

# Emission Control Device Operation, Diagnosis, and Service

**OBJECTIVES:** After studying Chapter 30, you should be able to:

- Prepare for the interprovincial Red Seal certification examination in Appendix VIII (Engine Performance) on the topics covered in this chapter.
- 2. Describe how the PCV system operates and how to diagnose a fault with the system.
- 3. List two methods for diagnosing problems with the AIR system.
- Describe how the evaporative emission control system works and how to test for its proper operation.
- **5.** Discuss the purpose and function of the EGR system and how to diagnose EGR operational problems.
- 6. Explain how to test a catalytic converter for obstructions and operating efficiency.
- 7. Describe the operation of a hybrid vehicle.
- 8. Explain the electrochemical reaction inside a fuel cell.

## AIR POLLUTION AND EMISSIONS CONTROL

Motor vehicles are major contributors to air pollution, which causes a number of health-related and environmental concerns. High concentrations of contaminants and smog were first noted in larger cities, usually in areas with limited air movement.

Automobile manufacturers, in cooperation with the federal government, began researching the causes and effects of vehicle emissions in the early 1960s. They determined that there are three main sources of automobile emissions:

- Exhaust emissions HC, CO and  $NO_x$
- Crankcase vapours HC
- Fuel evaporation HC

The factory installation of emission-control systems first started with California vehicles in 1961; Canada and the remaining U.S. states joined in a few years later. Federal laws were enacted to ensure that all automobiles, domestic and imported, must meet federal control standards before being offered for sale in Canada and the U.S.

## MAJOR POLLUTANTS

- Hydrocarbons (HC). Gasoline is made of hydrocarbons, which are consumed in the engine during the combustion process. Any condition that causes a misfire (or poor combustion) will raise HC levels. Ignition problems, very lean mixtures, and vacuum leaks are major causes of high HC. Fuel arrives at the engine as a hydrocarbon; if it leaves as unburned fuel, it's still a hydrocarbon.
- **Carbon monoxide (CO)** is formed when there is insufficient oxygen during combustion. CO is formed when one carbon atom from the fuel combines with one oxygen atom from the air. High CO readings are usually the result of an overly rich mixture.

CO is a poisonous gas that kills by replacing the oxygen in red blood cells. Never run an engine inside without fitting adequate exhaust extraction hoses.

• Oxides of nitrogen (NO<sub>x</sub>) are formed when nitrogen and oxygen from the air combine at



**Figure 30–1** Smog is ground-level ozone that looks like either smoke or fog.



**Figure 30–2** Notice the reddish-brown haze that is often seen over major cities.

very high temperatures; major  $NO_x$  formation begins at temperatures above  $1390^{\circ}C$  (2500°F). Any condition that raises combustion chamber temperatures will increase  $NO_x$ , e.g., lean airfuel mixtures, over-advanced ignition timing, and malfunctioning exhaust gas recirculation (EGR) systems.

Particulates, composed mainly of carbon, are a major pollutant with diesel engines. The black smoke from a diesel under acceleration is usually caused by a rich air-fuel mixture or a restricted air cleaner.

## SMOG

The common term used to describe air pollution is **smog**, a word that combines the two words *sm*oke and fog. See Figure 30–1. Smog is formed in the atmosphere when sunlight combines with unburned fuel (hydrocarbon, or HC) and oxides of nitrogen (NO<sub>x</sub>) produced during the combustion process. Smog is ground-level ozone (O<sub>3</sub>), a strong irritant to the lungs and eyes.

**NOTE:** Although upper-atmospheric ozone is desirable because it blocks out harmful ultraviolet rays from the sun, ground-level ozone is considered to be unhealthy smog.

## CONTROL OF EMISSIONS

• **HC (unburned hydrocarbons).** Excessive HC emissions (unburned fuel) are controlled by the evaporative system (charcoal canister), the positive crankcase ventilation (PCV) system, the air-pump system, and the catalytic converter.

- **CO** (carbon monoxide). Excessive CO emissions are controlled by the PCV system, the air-pump system, and the catalytic converter.
- NO<sub>x</sub> (oxides of nitrogen). Excessive NO<sub>x</sub> emissions are controlled by the exhaust gas recirculation (EGR) system and the catalytic converter. An oxide of nitrogen (NO) is a colourless, tasteless, and odourless gas when it leaves the engine, but as soon as it reaches the atmosphere and mixes with more oxygen, nitrogen oxides (NO<sub>2</sub>) are formed, which appear as reddish-brown. See Figure 30–2.
- Particulates. Excessive particulate emissions are controlled (on very recent diesels) with electronic fuel injection and new catalytic converters designed to eliminate particulate matter.

**HINT:** Exhaust emissions depend on the condition of the engine, ignition system, and fuel system as well as the proper operation of exhaust emission-control devices. Proper vehicle maintenance, including regular oil and oil filter, air filter, and fuel filter changes and other scheduled service, contributes to the ability of the engine to operate properly and produce the lowest possible emissions.

## POSITIVE CRANKCASE VENTILATION (PCV) SYSTEM

Most engines remove blow-by gases from the crankcase with a **positive crankcase ventilation** (**PCV**) system. This system pulls crankcase vapours



**Figure 30–3** A positive crankcase ventilation (PCV) system includes a hose from the air-cleaner assembly so that filtered air can be drawn into the crankcase. This filtered air is then drawn by engine vacuum through the PCV valve and into the intake manifold, where the crankcase fumes are burned in the cylinder. The PCV valve controls and limits this flow of air and fumes into the engine. The valve shuts in the event of a backfire to prevent flames from entering the crankcase area. (Courtesy of Chrysler Corporation)



**Figure 30–4** A dirty PCV vent filter inside the air cleaner housing. The air enters the crankcase through this filter and then is drawn into the engine through the PCV valve.

into the intake manifold, where they are sent to the cylinders with the intake charge. The vapours are then burned in the combustion chamber. Under some operating conditions, the blow-by gases are forced back through the inlet filter. See Figure 30–3.

**NOTE:** A blocked or plugged PCV system is a major cause of high oil consumption, and contributes to many oil leaks. Before expensive engine repairs are attempted, check the condition of the PCV system. See Figure 30–4.

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The owner of an older vehicle equipped with a V-6 engine complained to his technician that he smelled burning oil, but only *after* shutting off the engine. The technician found that the rocker cover gaskets were leaking. But why did the owner only notice the smell of hot oil when the engine was shut off? Because of the positive crankcase ventilation (PCV) system, engine vacuum tends to draw oil away from gasket surfaces. But when the engine stops, engine vacuum disappears and the oil remaining in the upper regions of the engine will tend to flow down and out through any opening. Therefore, a good technician should check an engine for oil leaks not only with the engine running but also shortly after shut-down.

## **PCV System Performance Check**

A properly operating positive crankcase ventilation system should be able to draw vapours from the crankcase and into the intake manifold. If the pipes, hoses, and PCV valve itself are not restricted, vacuum is applied to the crankcase. A slight vacuum is created in the crankcase (usually less than 25 mm [1 in.] Hg if measured at the dipstick) and is also applied to other areas of the engine. Oil drainback



**Figure 30–5** A typical positive crankcase ventilation (PCV) valve. A defective or clogged PCV valve or hose can cause a rough idle or stalling problem. Because the airflow through the PCV valve accounts for about 20% of the air needed by the engine at idle, use of the incorrect valve for an application could have a severe effect on idle quality.

holes provide a path for oil to drain back into the oil pan. These holes also allow crankcase vacuum to be applied under the cam or rocker covers and in the valley area of most V-type engines. There are several methods that can be used to test a PCV system.

## **The Rattle Test**

The rattle test is performed by simply removing the PCV valve and shaking it in your hand. See Figure 30–5.

- If the PCV valve does *not* rattle, it is definitely defective and must be replaced.
- If the PCV valve *does* rattle, it does not necessarily mean that the PCV valve is good. All PCV valves contain springs that can become weaker with age and heating and cooling cycles. Replace any PCV valve with the *exact* replacement according to vehicle manufacturers' recommended intervals, usually every 3 years or 60 000 km (36 000 miles).

## The Card Test

Remove the oil-fill cap (usually in the valve cover) and start the engine. See Figure 30–6.

**NOTE:** Use care on some overhead camshaft engines. With the engine running, oil may be sprayed from the open oil fill opening.

Hold a 75  $\times$  125 mm (3  $\times$  5 in.) card over the opening (any other piece of paper can be used for this test).

If the PCV system, including the valve and hoses, is functioning correctly, the card should be



**Figure 30–6** A typical PCV valve installed in a rubber grommet in the valve cover.

held down on the oil-fill opening by the slight vacuum inside the crankcase.

If the card will not stay, carefully inspect the PCV valve, hose(s), and manifold vacuum port for carbon build-up (restriction). Clean or replace as necessary.

**NOTE:** On some 4-cylinder engines, the card may vibrate on the oil fill opening when the engine is running at idle speed. This is normal because of the longer time intervals between intake strokes on a 4-cylinder engine.

## The Snap-Back Test

The proper operation of the PCV valve can be checked by placing a finger over the inlet hole in the valve when the engine is running and removing the finger rapidly. Repeat several times. The valve should "snap back." If the valve does not snap back, replace the valve.

## 🖩 AIR PUMP SYSTEM

An air pump provides the air necessary for the oxidizing process inside the catalytic converter. See Figure 30–7.

**NOTE:** This system is commonly called AIR, meaning **air injection reaction.** Therefore, an AIR pump does pump air.

On late model systems, a computer controls the airflow from the pump by switching on and off various solenoid valves. When the engine is cold, the air pump output is directed to the exhaust manifold to



**Figure 30–7** A typical belt-driven air pump. Air enters through the revolving fins. These fins act as a moving air filter because dirt is heavier than air and therefore the dirt in the air is deflected off the fins at the same time the air is drawn into the pump.

help provide enough oxygen to convert HC (unburned gasoline) and CO (carbon monoxide) to H<sub>2</sub>O (water) and  $CO_2$  (carbon dioxide). This also helps to heat the exhaust gas oxygen sensor. When the engine becomes warm and the engine is operating in closed loop, the computer operates the air valves to direct the air pump output to the catalytic converter. When the vacuum rapidly increases (above the normal idle level), as during rapid deceleration, the computer diverts the air pump output to the air cleaner assembly to silence the air. Diverting the air to the air cleaner prevents exhaust backfire during deceleration. See Figure 30–8. Three basic types of air pump are the belt-driven air pump, the pulse air-driven air pump, and the electric motor-driven air pump. All air-pump systems use one-way check valves to allow air to flow into the exhaust manifold and to prevent the hot exhaust from flowing into the valves on the air pump itself.

**NOTE:** These check valves commonly fail, resulting in excessive exhaust emissions (CO especially). When the check valve fails, hot exhaust can travel up to and destroy the switching valve(s) and air pump.



Figure 30–8 (a) When the engine is cold and before the oxygen sensor is hot enough to reach closed loop, the airflow is directed to the exhaust manifold(s) through one-way check valve(s). These valves keep exhaust gases from entering the switching solenoids and the air pump. (b) When the engine achieves closed loop, the airflow from the pump is directed to the check valve and catalytic converter.



Figure 30-9 A typical belt-driven air pump.

## **Belt-Driven Air Pumps**

The belt-driven air pump uses a centrifugal filter just behind the drive pulley. As the pump rotates, underhood air is drawn into the pump and slightly compressed. See Figure 30–9. The air is then directed to

- The exhaust manifold when the engine is cold to help oxidize CO and HC into carbon dioxide (CO<sub>2</sub>) and water vapour (H<sub>2</sub>O)
- The catalytic converter on many models to help provide the extra oxygen needed for the efficient conversion of CO and HC into CO<sub>2</sub> and H<sub>2</sub>O
- The air cleaner during deceleration or wideopen throttle (WOT) engine operation (see Figure 30–10)

## **Electric Motor-Driven Air Pumps**

This style of pump is generally used only during cold engine operation.

## **Pulse Air Devices**

The exhaust ports are normally under pressure from the burned exhaust leaving the cylinder. When the exhaust valve closes, the velocity of the escaping exhaust creates a vacuum in the port. This vacuum is used to draw fresh air from the air cleaner into the exhaust port. A one-way check valve prevents exhaust gases from reversing into the air cleaner when the exhaust valve opens and pressure returns. See Figure 30–11. Pulse air systems cannot be used with oxygen sensors.

# **Air Pump System Diagnosis**

The air pump system should be inspected if an exhaust emissions test failure occurs. In some cases, the exhaust will enter the air cleaner assembly, resulting in a rough running engine because the extra exhaust displaces the oxygen needed for proper combustion. With the engine running, check for normal operation:

Engine Operation	Normal Operation of a Typical Air Injection Reaction (AIR) Pump System
Cold engine (open-loop operation)	Air is diverted to the exhaust manifold(s) or cylinder head
Warm engine (closed-loop operation)	Air is diverted to the catalytic converter
Deceleration	Air is diverted to the air cleaner assembly
Wide-open throttle	Air is diverted to the air cleaner assembly

# **Visual Inspection**

Carefully inspect all air injection reaction (AIR) system hoses and pipes. Any pipes that leak air or exhaust require replacement. The check valve(s) should be checked when a pump has become inoperative. Exhaust gases could have leaked past the check valve and damaged the pump. Exhaust gas in the air cleaner is usually an indication of a leaking check valve. Check the drive belt on an enginedriven pump for wear and proper tension.

## Four-Gas Exhaust Analysis

An AIR system can be easily tested using an exhaust gas analyzer. Follow these steps:

- **1.** Start the engine and allow it to run until normal operating temperature is achieved.
- **2.** Connect the analyzer probe to the tail pipe and observe the exhaust readings for hydrocarbons (HC) and carbon monoxide (CO).
- **3.** Using the appropriate pinch-off pliers, shut off the airflow from the AIR system. Observe the HC and CO readings. If the AIR system is working correctly, the HC and CO should increase when the AIR system is shut off.
- 4. Record the  $O_2$  reading with the AIR system still inoperative. Unclamp the pliers and watch the  $O_2$  readings. If the system is functioning correctly, the  $O_2$  level should increase by 1 to 4%.



**Figure 30–10** The air pump supplies air to the exhaust port of each cylinder. Unburned hydrocarbons (HC) are oxidized into carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O), and carbon monoxide (CO) is converted to carbon dioxide (CO<sub>2</sub>).

**Figure 30–11** Cutaway of a pulse air-driven air device. It is used on many older engines to deliver air to the exhaust port through the use of the exhaust pulses acting on a series of one-way check valves. Air from the air cleaner assembly moves through the system and into the exhaust port, where the additional air helps reduce HC and CO exhaust emissions.





## EVAPORATIVE EMISSION CONTROL SYSTEM

The purpose of the **evaporative (EVAP)** emission control system is to trap and hold gasoline vapours. The charcoal canister is part of an entire system of hoses and valves called the **evaporative control system.** See Figure 30–12. Before the early 1970s, most gasoline fumes were simply vented to the atmosphere.

Charcoal or carbon granules have a natural tendency to absorb gasoline fumes (vapours) because carbon attracts carbon. See Figure 30–13. After being absorbed by the canister, the gasoline vapours are drawn by the engine vacuum back into the intake manifold to be burned (see Figures 30–14 and 30–15). This process of drawing in vapours from the charcoal canister is called **purging.** How much should be purged and when is controlled by a vacuum valve or a computer-controlled solenoid.

## **Diagnosing the EVAP System**

Before vehicle emissions testing began in many parts of the country, little service work was done on the evaporative emission system. Common engineperformance problems that can be caused by a fault in this system include:

- **Poor fuel economy.** A leak in a vacuum-valve diaphragm can result in engine vacuum drawing in a constant flow of gasoline vapours from the fuel tank. This usually results in a drop in fuel economy. Use a hand-operated vacuum pump to check that the vacuum diaphragm can hold vacuum.
- Poor performance. A vacuum leak in the manifold or ported vacuum section of vacuum hose in the system can cause the engine to run



**Figure 30–13** Some vehicles, especially trucks equipped with a carburetor or TBI, use a charcoal (carbon) filter inside the regular air filter located in the air cleaner housing. The purpose and function of this charcoal insert is to absorb evaporating fumes that occur when the engine is turned off. These fumes can come from the carburetor or intake manifold. When the engine is started, the normal airflow through the charcoal insert draws the gasoline fumes into the engine, where they are burned. Many fuel injection systems (from 2004 on) use a hydrocarbon absorber in the hose between the air cleaner and throttle body. This hydrocarbon trap is a thin-wall honeycomb disc that holds HC until the engine starts.



**Figure 30–14** A typical evaporative emission control system. Note that when the computer turns on the canister purge solenoid valve, manifold vacuum draws any stored vapours from the canister into the engine. Manifold vacuum also is applied to the pressure control valve and when this valve opens, fumes from the fuel tank are drawn into the charcoal canister and eventually into the engine. When the solenoid valve is turned off (or the engine stops and there is no manifold vacuum), the pressure control valve is spring loaded shut to keep vapours inside the fuel tank from escaping to the atmosphere.

rough. Age, heat, and time all contribute to the deterioration of rubber hoses.

Enhanced exhaust emissions (I/M 240) testing tests the evaporative emission system. A leak in the

system is tested by pressurizing the entire fuel system to 7 kPa (1 psi) with nitrogen, a nonflammable gas that makes up 78% of our atmosphere. The pressure in the system is then shut off and the pressure monitored. If the pressure drops below a set stan-



**Figure 30–15** This charcoal canister is mounted under the hood. Not all charcoal canisters are this accessible; in fact, most are hidden away under the hood or in other locations on the vehicle.

dard, then the vehicle fails the test. This test determines if there is a leak in the system.

**HINT:** To help diagnose leaks with the evaporative control system, start with a fuel tank that is threequarters full, or more. Minor leaks will show up faster when the volume of air in the tank is small: The pressure drops more quickly.

To test for proper airflow in the EVAP system, a **flow gauge** is required as shown in Figure 30–16. Most vehicle emission test sites require at least 1 L of volume per purge during the 240 second (4 minute) test. Many vehicles today are capable of flowing up to 10 L or more per minute.



# **Frequently Asked Question**

#### When Filling My Fuel Tank, Why Should I Stop When the Pump Clicks Off?

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Every fuel tank has an upper volume chamber that allows for expansion of the fuel when hot. The volume of the chamber is between 10 and 20% of the volume of the tank. For example, if a fuel tank had a capacity of 80 litres (20 gallons), the expansion chamber volume would be from 8 to 16 litres (2 to 4 gallons). A hose is attached at the top of the chamber and vented to the charcoal canister. If extra fuel is forced into this expansion volume. liquid gasoline can be drawn into the charcoal canister. This liquid fuel can saturate the canister and create an overly rich air-fuel mixture when the canister purge valve is opened during normal vehicle operation. This extrarich air-fuel mixture can cause the vehicle to fail an exhaust emissions test, reduce fuel economy, and possibly damage the catalytic converter. To avoid problems, simply add fuel to the next dime's worth after the nozzle clicks off. This will ensure that the tank is full, yet not overfilled.

## OBD II EVAPORATIVE CONTROL SYSTEMS

Part of the on-board diagnostic second generation (OBD II) standards includes monitoring for a leak in the evaporative control system (EVAP).

## **OBD II Evaporative Systems Monitor**

The EVAP system monitor tests for purge volume and leaks. Most applications purge the charcoal canister by venting the vapours into the intake manifold during cruise. To do this, the PCM typically opens a solenoid-operated purge valve installed in the purge line leading to the intake manifold.

A typical EVAP monitor first closes off the system to atmospheric pressure and opens the purge valve during cruise operation. See Figure 30–17. A fuel-tank pressure sensor then monitors the rate with which vacuum increases in the system. The monitor uses this information to determine the



purge volume flow rate. To test for leaks, the EVAP monitor closes the purge valve, creating a completely closed system. The fuel tank pressure sensor then monitors the leak-down rate. If the rate exceeds PCM-stored values, a leak greater than or equal to the OBD II standard of 1.0 mm (0.040 in.) exists. After two consecutive failed trips testing either purge volume or the presence of a leak, the PCM lights the MIL and sets a DTC.

DaimlerChrysler vehicles use an electric pump to pressurize the fuel system to check for leaks by having the PCM monitor the fuel-tank pressure sensor. See Figure 30–18. The fuel-tank pressure sensor is often the same part as the MAP sensor and instead of monitoring intake manifold absolute pressure, it is used to monitor fuel tank pressure.



**Figure 30–18** A DaimlerChrysler electric EVAP pressure pump located at the rear of the vehicle is used to pressurize the fuel tank and the PCM monitors for leaks.

## ТЕСН ТІР

#### **Always Tighten 3 Clicks**

Many diagnostic trouble codes (DTCs) are set because the gas cap has not been properly installed. To be sure that a screw-type gas cap is properly sealed, tighten the cap until it clicks three times. The clicking is a ratchet device and the clicking does not harm the cap. Therefore, if a P0440 or similar DTC is set, check the cap. Test caps can also be used when diagnosing the system as shown in Figure 30–19.



**Figure 30–19** An assortment of gas caps used during testing of the EVAP system.

## EXHAUST GAS RECIRCULATION SYSTEM

To reduce the emission of **oxides of nitrogen** ( $NO_x$ ), engines have been equipped with **exhaust gas recirculation (EGR)** valves. See Figure 30–20. From 1973 until recently, EGR valves were used on almost all vehicles. Because of the efficiency of computercontrolled fuel injection, some newer engines do not require an EGR system to meet emissions standards. Some engines use intake and exhaust valve overlap as a means of trapping some exhaust in the cylinder.

The EGR valve opens at speeds above idle on a warm engine. (NO<sub>x</sub> emissions are not high on a cold engine). When open, the valve allows a small portion of the exhaust gas (up to about 7%) to enter the intake manifold. Here, the exhaust gas mixes with and takes the place of some intake charge. This leaves less room for the intake charge to enter the combustion chamber. The recirculated exhaust gas is **inert** (chemically inactive) and does not enter into the combustion temperature. As the combustion temperature is lowered, the production of oxides of nitrogen is also reduced.

The EGR system has some means of interconnecting the exhaust and intake manifolds. See Figure 30–21. The interconnecting passage is controlled by the EGR valve. On V-type engines, the intake manifold crossover is used as a source of exhaust gas for the EGR system. A cast passage connects the exhaust crossover to the EGR valve. The gas is sent from the EGR valve to openings in the manifold. On inline-type engines, an external tube is generally used to carry exhaust gas to the EGR valve. This tube is often quite long so that the exhaust gas is cooled before it enters the EGR valve.



**Figure 30–20** Typical vacuum-operated EGR valve. The operation of the valve is controlled by the computer by pulsing the EGR control solenoid on and off.

## Positive and Negative Back Pressure EGR Valves

Many EGR valves are designed with a small valve inside that bleeds off any applied vacuum and prevents the valve from opening. Some EGR valves require a positive back pressure in the exhaust system. This is called a **positive back pressure** EGR valve. At low engine speeds and light engine loads, the EGR system is not needed, and the back pressure in it is also low. Without sufficient back pressure, the EGR valve does not open even though vacuum may be present at the EGR valve.

On each exhaust stroke, the engine emits an exhaust *pulse*. Each pulse represents a positive pressure. Behind each pulse is a small area of low pressure. Some EGR valves react to this low pressure area by closing a small internal valve, which allows the EGR valve to be opened by vacuum. This type of EGR valve is called a **negative back pressure** EGR valve. The following conditions must occur:

- 1. Vacuum must be applied to the EGR valve itself. This is usually ported vacuum on older, carburetor-equipped and some TBI fuel-injected systems. The vacuum source on later vehicles is often manifold vacuum controlled by the computer through a solenoid valve.
- **2.** Exhaust back pressure must be present to close an internal valve inside the EGR to allow the vacuum to move the diaphragm.

## **Electronic EGR**

Many engines since the mid-1990s have used computer-controlled solenoids or stepper motors (called linear EGR) to control the flow of exhaust into the intake manifold. See Figure 30–22 for an example of an assembly that uses three solenoids on a V-6 engine. The vehicle computer controls all three solenoids and can turn one, two, or all three on as necessary to provide the exact amount of EGR needed. Some vehicles use a linear EGR that contains a stepper motor to precisely regulate exhaust gas flow and a feedback potentiometer that signals the computer the actual position of the valve. See Figure 30–23.

## Diagnosing a Defective EGR Valve or System

If the EGR valve is not opening or the flow of the exhaust gas is restricted, then the following symptoms are likely:

- Ping (spark knock or detonation) during acceleration or during cruise (steady-speed driving)
- Excessive oxides of nitrogen (NO<sub>x</sub>) exhaust emissions

# TECH TIP

#### Watch Out for Carbon Balls!

Exhaust gas recirculation (EGR) valves can get stuck partially open by a chunk of carbon. The EGR valve or solenoid will test as defective. When the valve (or solenoid) is removed, small chunks or balls of carbon often fall into the exhaust manifold passage. When the replacement valve is installed, the carbon balls can be drawn into the new valve again, causing the engine to idle roughly or stall.

To help prevent this problem, start the engine with the EGR valve or solenoid removed. Any balls or chunks of carbon will be blown out of the passage by the exhaust. Stop the engine and install the replacement EGR valve or solenoid. Wear safety glasses or stay in the vehicle during this operation.



**Figure 30–22** This V-6 uses three solenoids for EGR. A scan tool can be used to turn on each solenoid. This will check whether the valve is working and if the exhaust passages are capable of flowing enough exhaust to the intake manifold to affect engine operation when cycled.





Figure 30–23 A linear EGR valve.

If the EGR valve is stuck open or partially open, then the following symptoms are likely:

- Rough idle or frequent stalling
- Poor performance/low power

The first step in almost any diagnosis is to perform a thorough visual inspection. To check for proper operation of a vacuum-operated EGR valve, follow these steps:

**1.** Check the vacuum diaphragm to see if it can hold vacuum.

**NOTE:** Because many EGR valves require exhaust back pressure to function correctly, the engine should be running at the specified RPM.

2. Apply vacuum from a hand-operated vacuum pump and check for proper operation. The valve itself should move when vacuum is applied, and the engine operation should be affected. The EGR valve should be able to hold the vacuum that was applied. If the vacuum drops off, then the valve is likely to be defective.

**NOTE:** Positive back-pressure EGR valves require that a certain amount of exhaust restriction be present to allow the valve to operate correctly. If low-restriction aftermarket or custom exhaust systems have been installed, the EGR valve may not function correctly. If the valve does not open or does not open enough, the engine will likely ping or spark knock during acceleration. Exhaust  $NO_x$  exhaust emissions are also likely to occur.

## DIAGNOSTIC STORY

#### The Blazer Story

The owner of a Chevrolet Blazer equipped with a 4.3 L, V-6 engine complained that the engine would stumble and hesitate at times. Everything seemed to be functioning correctly, except that the service technician discovered a weak vacuum going to the EGR valve at idle. This vehicle was equipped with an EGR valve-control solenoid, called an **electronic vacuum regulator valve** or **EVRV** by General Motors Corporation. The computer pulses the solenoid to control the vacuum that regulates the operation of the EGR valve. The technician checked the service manual for details on how the system worked. The technician discovered that vacuum should be present at the EGR valve only when the gear selector indicates a drive gear (drive, low, reverse). Because the technician discovered the vacuum at the solenoid to be leaking, the solenoid was obviously defective and required replacement. After replacement of the solenoid (EVRV), the hesitation problem was solved.

**NOTE:** The technician also discovered in the service manual that blower-type exhaust hoses should not be connected to the tail pipe on any vehicle while performing an inspection of the EGR system. The vacuum created by the system could cause false EGR valve operation to occur.

## DIAGNOSTIC STORY

## "I Was Only Trying to Help!"

On a Friday, an experienced service technician found that the driveability performance problem was a worn EGR valve. When vacuum was applied to the valve, the valve did not move at all. Additional vacuum from the handoperated vacuum pump resulted in the valve popping all the way open. A new valve of the correct part number was not available until Monday, yet the customer wanted the vehicle back for a trip during the weekend.

To achieve acceptable driveability, the technician used a small hammer and deformed the top of the valve to limit the travel of the EGR valve stem. The technician instructed the customer to return on Monday for the proper replacement valve.

The customer did return on Monday, but now accompanied by his lawyer. The engine had developed a hole in one of the pistons. The lawyer reminded the technician and the manager that an exhaust emission control had been modified. The result was the repair shop paid for a new engine and the technician learned always to repair the vehicle correctly or not at all.

# TECH TIP

## The Snake Trick

The EGR passages on many intake manifolds become clogged with carbon, which reduces the flow of exhaust and the amount of exhaust gases in the cylinders. This reduction can cause spark knock (detonation) and increased emissions of oxides of nitrogen  $(NO_x)$ .

To quickly and easily remove carbon from exhaust passages, cut an approximately 300 mm (1 ft) length from stranded wire, such as garage door guide wire or an old speedometer cable. Flare the end and place the end of the wire into the passage. Set your drill on reverse, turn it on, and the wire will pull its way through the passage, cleaning the carbon as it goes, just like a plumber's snake in a drain pipe.



**Figure 30–24** Typical catalytic converter. The small tube in the side of the converter comes from the air pump. The additional air from the air pump helps oxidize the exhaust into harmless  $H_2O$  (water) and  $CO_2$  (carbon dioxide).

If the EGR valve is able to hold vacuum, but the engine is not affected when the valve is opened, then the exhaust passage(s) must be checked for restriction. See the Tech Tip "The Snake Trick." If the EGR valve will not hold vacuum, the valve itself is likely to be defective and require replacement.

## OBD II EGR SYSTEM MONITOR

The OBD II EGR emission monitor uses a variety of methods to test EGR flow, depending on the manufacturer and the application. Most vehicles use the MAP sensor to test the EGR. During deceleration, the computer commands the EGR on and watches the MAP sensor response. The engine vacuum should decrease if the EGR flow is sufficient, and the MAP sensor should detect this drop in vacuum. If not enough change is noted, the test fails. The O2S sensor is also used by some systems to check the EGR. If the EGR efficiency level does not meet a predetermined standard after two consecutive trips, the computer lights the MIL and sets one or more DTCs.

## **CATALYTIC CONVERTERS**

An exhaust pipe connected to the manifold or header carries gases through a catalytic converter to the muffler and resonator (if used). In single exhaust systems used on V-type engines, the exhaust pipe is designed to collect the exhaust gases from both manifolds using a Y-shaped design. Vehicles with dual exhaust systems have a complete exhaust system coming from each of the manifolds. In most cases, the exhaust pipe must be made up in several sections so that it can be assembled in the space available under the vehicle.

The **catalytic converter** is installed between the manifold and the muffler to help reduce exhaust emissions. The converter has a heat-resistant metal housing. See Figure 30–24. A bed of catalyst-coated pellets or a catalyst-coated honeycomb grid is inside the housing.

## **Catalytic Converter Operation**

The converter contains small amounts of rhodium, palladium, and platinum. These elements act as catalysts (entities that start a chemical reaction without becoming a part of the chemical reaction). See Figure 30–25. As the exhaust gas passes through the catalyst, oxides of nitrogen  $(NO_r)$  are chemically reduced (that is, nitrogen and oxygen are separated) in the first section of the catalytic converter. This is called the reduction section. In the second section of the catalytic converter, most of the hydrocarbons and carbon monoxide remaining in the exhaust gas are oxidized to form harmless carbon dioxide  $(CO_2)$  and water vapour  $(H_2O)$ . This is called the oxidizing section. An air-injection system or pulse air system is used on some engines to supply additional air that may be needed in the oxidation process. See Figure 30-26. Since the early 1990s, many converters also contain cerium, an element that can store oxygen. The purpose of the cerium is to provide oxygen to the oxidation bed of the converter when the exhaust is rich and lacks enough oxygen for proper oxidation. When



Figure 30–25 A cutaway of a monolith substrate converter.



**Figure 30–27** This catalytic converter blew up when gasoline from the excessively rich running engine ignited. Obviously, raw gasoline was trapped inside and all it needed was a spark. No further diagnosis of this converter is necessary.



**Figure 30–26** A cutaway of a three-way catalytic converter showing the air tube in the centre of the reducing and oxidizing section of the converter. Note the small holes in the tube to distribute air from the AIR pump to the oxidizing rear section of the converter.

the exhaust is lean, the cerium absorbs the extra oxygen. The converter must have a varying rich-tolean exhaust for proper operation:

- A rich exhaust is required for reduction—stripping the oxygen (O<sub>2</sub>) from the nitrogen in NO<sub>x</sub>
- A lean exhaust is required to provide the oxygen necessary to oxidize HC and CO (combining oxygen with HC and CO to form H<sub>2</sub>O and CO<sub>2</sub>)

Early catalytic converters are oxidizing only: helping to control HC and CO. They are know as twoway converters. Later converters added a reduction section that helps to control  $NO_x$ . These are known as three-way converters.

If the catalytic converter is not functioning correctly, check to see that the air-fuel mixture being supplied to the engine is correct and that the ignition system is free of defects.

## Nitrogen-Oxide-Adsorptive Catalytic Converters

Conventional three-way converters are not effective in converting  $NO_x$  into nitrogen when exces-

# Frequently Asked Question ???

# Can a Catalytic Converter Be Defective Without Being Clogged?

Yes. Catalytic converters can fail by being chemically damaged or poisoned without being mechanically clogged. Therefore, the catalytic converter should not only be tested for physical damage (clogging) by performing a back-pressure or vacuum test and a rattle test but also for temperature rise, usually with a pyrometer or propane test, to check the efficiency of the converter.

sive oxygen from lean mixtures is present. NOA converters attract  $NO_x$  molecules during lean operating conditions and release them when the mixture richens.

## **Four-Way Converters**

Late in 2004, California became the first state to approve a regulation reducing carbon dioxide  $(CO_2)$  emissions from vehicle exhaust. Canada and the other states are expected to follow. The new regulation becomes effective with 2009 vehicles.

## **The Tap Test**

This simple test involves tapping (not pounding) on the catalytic converter using a rubber mallet. If the substrate inside the converter is broken, the converter will rattle when hit. If the converter rattles, a replacement converter is required. See Figure 30–27.

# Testing Back Pressure with a Vacuum Gauge

A vacuum gauge can be used to measure manifold vacuum at a high idle (2000 to 2500 rpm). If the exhaust system is restricted, pressure increases in the exhaust system. This pressure is called **back pressure**. Manifold vacuum will drop gradually if the engine is kept at a constant speed and the exhaust is restricted.

The reason the vacuum will drop is that all the exhaust leaving the engine at the higher engine speed cannot get through the restriction. After a short time (within 1 minute), the exhaust tends to pile up above the restriction and eventually remains in the cylinder of the engine at the end of the exhaust stroke. Therefore, at the beginning of the intake stroke, when the piston traveling downward should be lowering the pressure (raising the vacuum) in the intake manifold, the extra exhaust in the cylinder *lowers* the normal vacuum. If the exhaust restriction is severe enough, the vehicle can become undriveable because cylinder filling cannot occur except at idle.

# Testing Back Pressure with a Pressure Gauge

Exhaust system back pressure can be measured directly by installing a pressure gauge in an exhaust opening. This can be accomplished in one of the following ways:

1. To test at an oxygen sensor opening, remove the inside of an old, discarded oxygen sensor and thread in an adapter to connect it to a vacuum or pressure gauge.

**NOTE:** An adapter can be easily made by inserting a metal tube or pipe. A short section of brake line works great. The pipe can be brazed to the oxygen sensor housing or it can be glued with epoxy. An 18 mm compression gauge adapter can also be adapted to fit into the oxygen sensor opening. See Figure 30–28.

- **2.** To test at an exhaust gas recirculation (EGR) valve, remove the EGR valve and fabricate a plate.
- **3.** To test at an air injection reaction (AIR) check valve, remove the check valve from the exhaust tubes leading to the exhaust manifold. Use a rubber cone with a tube inside to seal against the exhaust tube. Connect the tube to a pressure gauge.

At idle the maximum back pressure should be less than 10 kPa (1.5 psi), and it should be less than 15 kPa (2.5 psi) at 2500 rpm.



**Figure 30–28** A back pressure tool can be easily made by attaching a short section of brake line to the shell of an old oxygen sensor. Braze or epoxy the tube to the shell.

# Testing a Catalytic Converter for Temperature Rise

A properly working catalytic converter should be able to reduce  $NO_x$  exhaust emissions into nitrogen (N) and oxygen (O<sub>2</sub>) and oxidize unburned hydrocarbon (HC) and carbon monoxide (CO) into carbon dioxide (CO<sub>2</sub>) and water vapour (H<sub>2</sub>O). During these chemical processes, the catalytic converter should increase in temperature at least 10% if the converter is working properly. To test, operate the engine at 2500 rpm for at least 2 minutes to fully warm up the converter. Measure the inlet and the outlet temperatures as shown in Figure 30–29.

**NOTE:** If the engine is extremely efficient, the converter may not have any excessive unburned hydrocarbons or carbon monoxide to convert! In this case, a spark plug wire could be grounded out using a vacuum hose and a test light (see Chapter 21) to create some unburned hydrocarbon in the exhaust. This will heat the converter. Do not ground out a cylinder for longer than 10 seconds or the excessive amount of unburned hydrocarbon could overheat and damage the converter.

## OBD II Catalytic Converter Monitor

The catalytic converter monitor of OBD II uses an upstream and downstream heated oxygen sensor (HO2S) to test catalytic efficiency. See Figure 30–30. When the engine combusts a lean air-fuel mixture, higher amounts of oxygen flow through the exhaust into the converter. The catalyst materials absorb this oxygen for the oxidation process, thereby removing it from the exhaust stream. If a converter cannot absorb enough oxygen, oxidation does not occur. Engineers established a correlation



**Figure 30–29** The temperature of the outlet should be at least 10% hotter than the temperature of the inlet. This converter is very efficient. The inlet temperature is 230°C (450°F). Ten percent of 230°C is 23°C (450°F, 45°F). In other words, the outlet temperature should be at least 253°C (495°F) for the converter to be considered okay. In this case, the outlet temperature of 274°C (525°F) is more than the minimum 10% increase in temperature. If the converter is not working at all, the inlet temperature will be hotter than the outlet temperature.

between the amount of oxygen absorbed and converter efficiency.

The OBD II system monitors how much oxygen the catalyst retains. A voltage waveform from the downstream HO2S of a good catalyst should have little or no activity. See Figure 30–31. A voltage waveform from the downstream HO2S of a degraded catalyst shows a lot of activity. In other words, the closer the activity of the downstream HO2S matches that of the upstream HO2S, the greater the degree of converter degradation. In operation, the OBD II monitor compares activity between the two exhaust oxygen sensors.

## Diesel Particulate Catalytic Converters

Diesel exhaust contains some HC and  $NO_x$ , but excess particulates are the main emissions. There are a number of diesel converters that use high internal temperatures to incinerate the particulates and turn them into ash.



Figure 30–30 The OBD II catalytic converter monitor compares the signals of the upstream and downstream oxygen sensors to determine converter efficiency.



Figure 30–31 The waveform of an O2S downstream from a properly functioning converter shows little, if any, activity.

#### ТЕСН ТІР

### **Catalytic Converters Are Murdered**

Catalytic converters start a chemical reaction but do not enter into the chemical reaction. Therefore, catalytic converters do not wear out and they do not die of old age. If a catalytic converter is found to be defective (nonfunctioning or clogged), look for the root cause. Remember this:

"Catalytic converters do not commit suicide they're murdered."

Items that should be checked when a defective catalytic converter is discovered include all components of the ignition and fuel systems. Excessive unburned fuel can cause the catalytic converter to overheat and fail. The oxygen sensor must be working and fluctuating from 0.5 to 5 Hz to provide the necessary air-fuel mixture variations for maximum catalytic converter efficiency.

## DIESEL EMISSION CONTROLS

Diesel engines have no throttle plate; they take in far more air than is needed, except during the maximum power demands. Because of this, combustion is very complete compared to a gasoline engine, and emissions differ. See Figure 30–32.

Hydrocarbons (HC) and carbon monoxide (CO) emissions are generally low. Oxides of nitrogen  $(NO_r)$ may be present because of the high temperatures and pressures during combustion; however, the worst emission is particulate matter. Particulates, composed primarily of carbon, are visible (black



REASON FOR LOW HC AND CO EMISSION

Figure 30–32 Excess air in a diesel engine contributes to a more complete combustion. (Courtesy Ford Motor Co.)

#### **AIR/FUEL MIXTURE**

smoke) and are created by incomplete combustion. Rich fuel mixtures or an air intake restriction are common causes of increased particulate formation.

Federal emission standards for diesel engines began in 1988 and have become more stringent since that time. As an example, particulate emission limits were lowered from 60 grams per brake horsepowerhour in 1988 to 10 grams per horsepower-hour in 1994. This required the need for catalytic converters on some exhaust systems.

In 1997, OBD II standards for diesel engines were introduced; EGR systems were now monitored and in 1998, engine misfire and glow plug malfunctions were added. A malfunction indicator lamp (MIL) on the instrument panel turns on to indicate a system deterioration or failure.

Diesel engines are analyzed with an opacity meter (clamped to the exhaust pipe), which uses a light beam to measure exhaust density under different operating modes. Common emission controls include catalytic converters for particulates, EGR valves for  $NO_x$ , and crankcase depression regulator valves, a form of PCV valve used to control crankcase hydrocarbon emissions.

Diesel palladium-oxidation particulate-reduction converters require low-sulphur diesel fuel, which was mandated in Canada beginning in 1995. Highsulphur fuels will render the converter inactive. Bosch and a number of European manufacturers have developed a new sintered metal (vs. traditional ceramic) particulate-filter converter that is expected to last for the life of the vehicle. Production is expected to begin in 2005–2006.

The introduction of electronically controlled fuel injection assures a more precise fuel delivery that brings emissions to an even lower level.

## EMISSIONS TESTING CENTRES

The British Columbia AirCare and the Ontario Drive Clean programs are designed to identify vehicles with high emissions, and to improve air quality by reducing harmful pollutants. Drive Clean inspects vehicles in southern and eastern Ontario, while Air-Care covers the Greater Vancouver and Fraser Valley regions, areas in both provinces experiencing air pollution problems. Although there are differences between the two programs, they are similar. The following is typical.

- Older vehicles, prior to 1991 must be checked every year during a steady state 40 km/h (25 mph) tailpipe test.
- Newer vehicles, from 1992 to date, are inspected every two years. They go through a more comprehensive test. See Figure 30–33.

- Maximum allowable emissions, listed as parts per million (ppm), percent (%) or grams per kilometre (g/km), vary with the year and model of the vehicle. See Figure 30–34.
- New vehicles are exempt for the first year (or first two years).
- The vehicle must either pass the test or have a conditional pass before licence plates will be issued.

Vehicles brought to the test centre are checked visually for a catalytic converter, the gas cap is removed for pressure testing and the vehicle exhaust is measured for hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen  $(NO_x)$  while running at speed on a dynamometer. Special dynamometers are often used for all-wheel drives. See Figure 30–35.

Owners of vehicles that fail the test will receive a conditional pass if they have the vehicle diagnosed and repaired by an AirCare Certified technician at an AirCare certified repair centre. There is a repair cost limit designed to ensure emissions are reduced while limiting the financial burden for the owner. Ontario has a fixed limit; British Columbia's limit is tied to the model year.

Vehicles repaired by a non-certified shop will not qualify for a conditional pass; the vehicle must be reinspected till it passes.

Certified technicians must pass a comprehensive examination on emissions control, gas analysis, diagnosing, electronics and engine management for gasoline engines. Diesel and alternate fuel examinations may be taken at the same time.

Older vehicles typically account for a high percentage of failed vehicles. Later vehicles, especially if equipped with OBD II on-board diagnostics, account for a very low percentage of failures; 2005 vehicles are 98% cleaner than 1970 vehicles.

Because of this, Ontario plans to phase out the Drive Clean program by 2008; AirCare is considering testing older vehicles only, starting in 2006.

## ADVANCED VEHICLES

## The Road to Zero Emissions

In 1990, the California Air Resources Board (CARB) adopted a requirement that 10% of the new cars offered for sale in California from 2003 on would have to be zero emission vehicles (ZEV): cars and trucks that produce no evaporative or exhaust emissions.

This was later reduced to 4% ZEVs, provided the remaining 6% are clean enough to qualify as partial ZEVs. The 4% ZEV level may be further reduced to 2% in the future.



**Figure 30–33** Emissions testing procedure. (Reprinted with permission from Pacific Vehicle Testing Technologies Ltd., operators of the BC AirCare Program. All rights reserved.)

# AirCare Vehicle Inspection Report

Thanks for doing your part for clean air! Since 1992, your efforts have reduced vehicle emissions by 66%.

			INSPECTION RESULTS					FINAL RESULT	
TEST DATE	TESTTIME	AMOUNT PAID	EXHAUST EMISSIONS	CATALYTIC CONVERTER PRESENCE	GAS CAP PRESENCE	GAS CAP PRESSURE			
18-FEB-2004	15:36:18	\$23.00	PASS	PASS	PASS	PASS	V	PASS	
			VELUCI	E INICODIA	ATION			and the second se	

#### VEHICLE INFORMATION

Registration Number	Vehicle Year	Vehicle Make	Registered Curb Weight	Vehicle Identification Number (VIN)	Vehicle Type	Engine Síze	Odometer	AIRCARE EXPIRY DATE:
7121374	1991	ΤΟΥΤ	1385	JT2VV22F3M	LDGV	2.5	71 ,000	15-FEB-2005

#### HOW TO UNDERSTAND YOUR AIRCARE VEHICLE INSPECTION REPORT

The "Maximum Allowables" indicate the point above which the results become a "Fail". The "Average Passing Reading" value represents the average result for vehicles of the same year, type (car or truck), make and engine as your vehicle, calculated from actual AirCare test results.

DRIVING TEST		Maximum Allowable	Vehicle Reading	Average Passing Reading	RESULT
Hydrocarbons (HC)	ppm	89.00	5.00	13.50	PASS
Carbon Monoxide (CO)	%	0.68	0.00	0.03	PASS
Oxides of Nitrogen (NOx	) ppm	1007	364.00	259.50	PASS
Opacity (Diesel Only)					
IDLE TEST		Maximum	Vehicle	Average Passing	RESULT

IDLE TEST		Allowable	Reading	Reading	RESULT
Hydrocarbons (HC)	ppm	107	2	8	PASS
Carbon Monoxide (CO)	%	0.81	0.00	0.02	PASS

Results close to, or better than, the "Average Passing Reading" level means your vehicle is a normal emitter for its age and type. Readings above the average, but still below the "Maximum Allowable", may indicate that key emission controls are degrading to the point where your vehicle may fail in the future.

GENERAL INFORMATION	
-Your vehicle has passed. -This report may be necessary when licensing this vehicle.	
FOR OFFICE USE ONLY	
For more information about your AirCare test, see reverse or visit www.aircare.ca	FORM #7002 REV 6/2004

**Figure 30–34** Vehicle emission inspection report. (Reprinted with permission from Pacific Vehicle Testing Technologies Ltd., operators of the BC AirCare Program. All rights reserved.)



**Figure 30–35.** (a) Typical enhanced exhaust emission testing facility. The sign says to leave the engine running. (b) Vehicle being "driven" on the dynamometer. The driver is following a trace displayed on a television screen. (c) The gas cap is tested for leakage. (d) The final report is printed and given to the driver.

## **Electric Vehicles**

Battery-powered electric vehicles were the first choice of most automakers to meet the new ZEV rules. Electric motors produce maximum power at 0 rpm and work well for around town transportation. The downside is a limited driving range of 80 to 160 km (50 to 100 mi), time for battery recharging, and the space required for a very heavy battery pack.

As an example, the Ford Ranger EV pickup truck (see Figure 30–36) has 39 8 volt lead-acid battery modules that weigh almost 900 kg (2000 lb). Connected in series, the battery pack produces over 300 volts to power the drive motor. See Figure 30–37. Switching to very expensive nickel-metal hydride batteries (25 12-volt modules) reduced the battery pack weight to 590 kg (1300 lb) and increased the driving range from 80 km (50 mi) to 130 km (80 mi). The Ranger was the only major EV imported into Canada. It is now discontinued. By the year 2000, DaimlerChrysler, Ford, G.M., Honda, Nissan, and Toyota were all manufacturing electric vehicles. This ended shortly after for a number of reasons: relaxed CARB ZEV rules, low consumer demand, high initial costs, and concerns that ZEVs are not really zero emission vehicles, as emissions are often generated at the power company producing electricity to charge the batteries. These are called indirect emissions.

# **Hybrid Vehicles**

Hybrids are the combination of a gasoline internal combustion engine and an electric motor. A smaller gasoline engine, which increases fuel economy and lowers emissions, can then be used; the electric motor power is brought in during high load conditions. The total power of the engine and the motor cannot be added together, as gasoline engines produce maximum



Figure 30–36 A Ford Ranger electric truck uses 39 batteries mounted under the pickup bed. (Courtesy Ford Motor Co.)



**Figure 30–37** A typical motor/transaxle unit; torque is controlled by varying the amount of current flowing through the stator. The motor also charges (regenerates) the battery pack during braking. (Courtesy Ford Motor Co.)

power at higher RPM, while electric motors produce maximum power at 0 rpm. See Figure 30–38.

## Series and Parallel Hybrids

Series hybrids use the engine to drive a generator, which in turn powers an electric motor that drives the wheels. Parallel hybrids use both the engine and the electric motor to propel the vehicle. See Figure 30–39.

## **Extensive Testing**

Both Honda and Toyota carried out extensive testing in Japan before releasing the cars for sale in Canada and the U.S. Almost 50 000 hybrids were sold in Japan during the three years prior to North American introduction.

## **Honda Insight and Civic**

Honda calls their system Integrated Motor Assist (IMA). The Insight uses a small 1.0-litre, 3-cylinder aluminum engine as the main power source; an electric motor mounted in the bell housing supplies additional power assist during high load conditions and acceleration. See Figures 30–40 and 30–41. The electric motor also functions as a generator during braking and deceleration to keep the 144 volt NiMH

**Figure 30–38** Combined power output of a Honda Integrated Motor Assist (IMA) hybrid. Note the electric motor produces maximum power at low RPM and the gasoline engine at high RPM. (Courtesy Honda Canada Inc.)



## Series Hybrid System

In the series hybrid system, the engine runs a generator, and the generated electricity enables the electric motor to drive the wheels. This type of vehicle can be described as an electric car that is equipped with an engine-driven generator.

Equipped with a low-output engine, the engine is operated at a practically constant speed in its most effective range, in order to efficiently recharge the battery while the vehicle is in motion.

## Parallel Hybrid System

This system, using both the engine and the electric motor to directly drive the wheels, is called the parallel hybrid system. In addition to supplementing the motive force of the engine, the electric motor in this system can also serve as a generator to recharge the battery while the vehicle is in motion.







**Figure 30–40** The Honda Insight IMA system mounts the ultra-compact electric motor in the bell housing. The motor functions as an assist motor, a generator and a starter. (Courtesy Honda Canada Inc.)



**Figure 30–41** The major components of the Honda IMA system are the motor, the high voltage cables, and the Intelligent Power Unit (batteries and controls). (Courtesy Honda Canada Inc.)

battery pack charged. If the battery pack shows a low state of charge, the motor will continue the generator function at idle. No outside charging is required.

The engine will automatically shut off when coming to a stop unless the air conditioning is on, the batteries are low, or an electrical load exists (i.e., headlights on). The IMA motor will restart the engine when the accelerator pedal is depressed (with the clutch disengaged). A conventional 12 volt starter and battery are used only under abnormal conditions, such as a low battery-module state of charge.

The Insight is a lightweight aluminum-bodied twoseater that ranks as the most fuel-efficient gasolinepowered automobile sold in North America. See Figure 30–42.

The Civic is a larger four cylinder, four-seat automobile that also enjoys excellent fuel economy and low emissions. Most of the Insight IMA features also apply.

## **Toyota Prius**

The Toyota Prius hybrid uses a slightly different concept. See Figures 30–43 and 30–44. Two electric motors mounted in the transaxle assembly are used to both drive the vehicle and charge the 274 volt NiMH battery pack. See Figure 30–45. One motor (MG2) drives the wheels on acceleration and charges the batteries during deceleration. The second motor (MG1) supplies electricity to MG2 to drive the wheels. It also functions both as a starter and a generator to charge the batteries. There is no auxiliary 12 volt starter. The Toyota hybrid has the ability to operate with only the electric motor or a combination of electric motor and engine. See Figure 30–46.

The engine stops automatically when the vehicle comes to a stop, unless the air conditioning is on, the engine is cold, or the batteries are at a low state of charge. A 12 volt battery is used to power body electrical components and lighting.

The Prius is an extremely clean vehicle that exceeds CARB super ultra-low emission vehicle (SULEV) standards for CO, HC and  $NO_x$  while still achieving excellent fuel economy and driveability.



Figure 30-42 The Honda Insight battery pack is mounted in the trunk area. (Courtesy Honda Canada Inc.)





and electric motors into a single powertrain assembly. (Courtesy Toyota Canada Inc.)





Figure 30-46 Operating modes of the Toyota Prius hybrid. (Courtesy Toyota Canada Inc.)

## 📓 SAFETY

Only trained technicians are allowed to service the high voltage circuits in any hybrid. Special training, insulated wearing apparel and tools are needed to work safely in this area. In 2004, as an example, Toyota raised their hybrid operating voltage from 274 to almost 500 volts! Follow all safety instructions to the letter.

## **Industry Support**

While Toyota and Honda were the first major manufacturers to build hybrids, many other domestic and import automakers have now joined their ranks. Ford released the Escape hybrid for 2005; GM joined with diesel/hybrid transit buses in 2004 and the Silverado hybrid pickup truck in 2005. GM also plans a hybrid Saturn Vue in 2006. DaimlerChrysler is currently testing this technology with the Dodge Durango and Jeep Liberty. Asian carmakers are moving into larger vehicles such as the Toyota Camry, Honda Civic, and Lexus SUV.

## **Fuel Cell Vehicles**

Very simply put, a fuel cell vehicle is an electric vehicle powered by an electricity generating fuel cell, rather than a battery pack.

A fuel cell is a device that produces electricity from hydrogen (in our example), leaving nothing behind except heat and water. See Figures 30–47 and 30–48.

Fuel cells generate electricity from an electrochemical process using hydrogen as a fuel. See Figure 30–49. Compressed hydrogen is pumped into the fuel cell at the anode, the negative side of the cell. Oxygen (in the air) enters the cell from the opposite side at the cathode, the positive side of the cell. The oxygen attracts the hydrogen. The two are separated by a thin electrolytic membrane of polymer material.

A platinum powder catalyst in the cell begins a reaction that strips the hydrogen of its electrons; only the positive charged hydrogen ions (protons) can pass through the membrane into the positive side of the cell. This leaves the negative charged electrons behind. A voltage potential now exists between the two





sides of the cell. Electrons (current) flowing through a circuit (connecting the positive and negative sides) power an electric motor to drive the wheels.

The electrons (-), now at the cathode, join with the hydrogen ions (+) and oxygen at a second platinum powder catalyst; a reaction occurs. Water and heat are the only products: no emissions.

## When?

Almost every major automaker is developing a fuel cell vehicle. Some, such as Toyota and G.M., are using their own in-house technologies; others, such as Ford, DaimlerChrysler and Honda, are using fuel cells pioneered by a Canadian company, Ballard Power Systems of Burnaby, British Columbia.

Many of these car companies have working prototypes currently being tested; however, full production is still about ten years away. Reduced costs, improved reliability, and fuel availability are concerns still to be addressed.



Figure 30–49 Compressed hydrogen, stored at a hydrogen refueling station, is pumped into a fuel tank in the vehicle. It initially arrives at the station as either compressed hydrogen, clean hydrocarbon fuel or natural gas. (Courtesy Toyota Canada Inc.)

# PHOTO SEQUENCE 21 Testing a Vacuum-Operated EGR Valve



**P21–I** A cutaway of a typical vacuum-operated exhaust gas recirculation (EGR) valve.



**P21–2** When the engine operates at idle speed, it should stall if the EGR valve is opened by hand. The technician should use a glove or shop cloth to prevent the possibility of being burned on the hot EGR valve.



**P21-3** An EGR valve can also be tested off the vehicle by applying vacuum from a hand-operated vacuum pump. The diaphragm of the valve should move when vacuum is applied, and the vacuum should hold if the valve is okay.



**P21–4** This is a negative back-pressure EGR valve because the vacuum dropped to zero when shop air (compressed air) was blown over the end of the EGR valve pintle. A positive back-pressure EGR valve would require the air pressure to close an internal valve to allow the valve to open when vacuum was applied to the diaphragm.



**P21–5** All EGR valve passages should be checked for carbon blockages that can prevent the valve from flowing enough exhaust gas to reduce  $NO_x$  exhaust emissions.



**P21–6** All EGR passages in the intake manifold should also be checked for carbon and cleaned out if restricted. Use a vacuum cleaner to help get all of the pieces of carbon out of the passages.

## SUMMARY

- 1. The positive crankcase ventilation (PCV) system pulls blow-by gases and crankcase vapours into the intake manifold.
- **2.** The PCV valve allows a metered amount of manifold vacuum to be applied to the crankcase. The valve can be tested by rattling the valve or by using a card over the oil fill opening.
- **3.** An AIR pump supplies air to the exhaust manifold when the engine is cold and to the catalytic converter when the engine achieves closed-loop operation.
- **4.** The evaporative emission control (EVAP) system uses a charcoal (carbon) canister and various hoses and lines to trap and hold gasoline fumes and to prevent these fumes from escaping into the atmosphere.
- **5.** The exhaust gas recirculation (EGR) system bleeds some inert exhaust gases into the combustion chamber to prevent the higher peak temperature that could occur. The main purpose and function of the EGR system is to reduce the formation of oxides of nitrogen  $(NO_x)$  exhaust emissions.
- **6.** A catalytic converter is used in the exhaust system to start a chemical reaction among the exhaust gases but the catalysts are not consumed by the reaction. Its function is to separate  $NO_x$  exhaust emissions into nitrogen (N) and oxygen ( $O_2$ ). The other part of the converter is designed to oxidize hydrocarbons (HC) and carbon monoxides (CO) into harmless  $CO_2$  and  $H_2O$  (water vapour).
- 7. Hybrid vehicles use a combination of a smaller internal combustion engine and an electric drive motor. Fuel cells convert hydrogen gas into electricity to power an electric drive motor.

## 

- 1. List three tests that can be performed to check the PCV system.
- **2.** Describe how to test an AIR system using an exhaust gas analyzer.
- **3.** Explain how to perform a pressure test on an evaporative control system.
- **4.** List three methods that can be used to test an EGR valve and system.
- **5.** Describe three tests that can be used to test the condition of a catalytic converter.

## RED SEAL CERTIFICATION-TYPE QUESTIONS

- 1. Positive crankcase ventilation (PCV) systems help to control \_\_\_\_\_.
  - **a.** Particulates
  - b. Hydrocarbons

- c. Oxides of nitrogen
- **d.** Carbon dioxide
- **2.** An air pump system with a defective one-way exhaust check valve could \_\_\_\_\_.
  - **a.** Create an external exhaust leak
  - b. Cause exhaust back-pressure to decrease
  - **c.** Cause the air pump to fail
  - d. Reduce engine power during cold operation
- **3.** The charcoal canister can become saturated with gasoline by \_\_\_\_\_.
  - **a.** Overfilling the fuel tank
  - b. Leaking fuel injectors
  - $\mathbf{c.}\ \mathbf{Excessive}\ \mathbf{fuel}\ \mathbf{injection}\ \mathbf{pressure}$
  - d. Leaving the gasoline filler cap loose
- 4. Positive back-pressure EGR valves
  - a. Operate at idle
  - b. Require low exhaust back pressure to open
  - c. Need exhaust back pressure to function
  - **d.** Operate only when the coolant temperature is below 50°C (122°F)
- **5.** A partially clogged EGR passage could cause the vehicle to fail an emissions test for \_\_\_\_\_.
  - **a.** Oxides of nitrogen
  - **b.** Excessive hydrocarbons
  - c. Carbon monoxide
  - **d.** Particulates
- 6. Catalytic converters can be damaged by
  - a. Long periods of idle
  - b. Pulling a trailer
  - c. An ignition misfire
  - d. High engine RPM
- 7. A good catalytic converter should be
  - **a.** Hotter at the outlet than at the inlet
  - **b.** Hotter at the inlet than at the outlet
- 8. Smog is formed in the atmosphere when oxides of nitrogen combine with \_\_\_\_\_.
  - a. Carbon monoxide
  - b. Hydrocarbons
  - **c.** Carbon dioxide
  - d. Particulate matter
- **9.** Diesel engines are tested with an opacity meter that passes a light beam through the exhaust gases at the tailpipe. This measures
  - a. Exhaust volume
  - **b.** Exhaust density
  - c. Carbon monoxide levels
  - d. Excessive back pressure
- ${\bf 10.} \ {\rm Hybrid} \ {\rm vehicles} \ {\rm reduce} \ {\rm total} \ {\rm exhaust} \ {\rm emission} \ {\rm because}$ 
  - **a.** The engines are very efficient
  - $\boldsymbol{b.}$  They only carry two passengers
  - c. The batteries are charged overnight
  - **d.** A smaller internal combustion engine can be used