into thin air

part one

A major feature of the OBD-II system is its ability to monitor the evaporative emissions system. While the system still has a few wrinkles that must be ironed out, an OBD-II equipped vehicle's ability to identify problems in the evaporative system provides the service technician with information not available during a regular tailpipe tests. One of the reasons this feature was added is that an eventual OBD-II goal is to do away with emissions testing and replace it with a check of the vehicle's computer system.

Evaporative emissions refers to the pollutants emitted into the atmosphere through evaporation. In the past, carburetors and gas tanks were the biggest contributors to evaporative emissions. With current emissions standards, carburetors have largely disappeared, so the gas tank is now the primary contributor to evaporative emissions.

To understand how much a fuel tank can contribute to evaporative emissions, try comparing evaporative to tailpipe emissions. A properly running modern vehicle produces tailpipe emissions of less than 1/3-gram of hydrocarbons per mile driven. A 0.040-inch hole in a gas tank (above the liquid fuel level) or a gas cap leak of the same size can produce a running fuel vapor loss of approximately 1.35 grams of hydrocarbons per mile. A 0.040-inch hole for vapor is not a very big leak, so it's staggering to think how much hydrocarbon emissions a *missing* gas cap would produce. So if we truly want the car to run clean, it is important to monitor the entire fuel containment system for leaks.

The evaporative emissions control system can be broken down into two subsystems: the *purge system* and the *evaporative containment system*. The *evaporative containment system* is the portion that controls the evaporation of hydrocarbons from the fuel tank as well as allowing the tank to vent. A charcoal canister is used as the containment mechanism, and it is connected to the fuel tank via steel, neoprene and/or plastic lines. The *purge system* removes hydrocarbons from the charcoal canister, then carries them into the intake manifold, so they can be drawn into the combustion chambers and burned.

The canister is the heart of the evaporative containment system. Canisters vary greatly in construction, but all contain a common main ingredient: activated charcoal. Activated charcoal is a carbon compound that readily *adsorbs* hydrocarbons. No, that's not a typo for *absorb*. The words *adsorb* and *absorb* describe two different types of chemical processes.

When a vapor or fluid is merely taken up and stored on the microsurface of a solid like the charcoal, this is *adsorption*. *Absorption*, on the other hand, can involve a chemical change of the materials, such as a solution. In the evaporative system, the canister merely stores the fuel vapors until the next time the engine is ready to accept them. So the word we want is *adsorb.*

This system allows the fuel tank to vent through the canister as fuel vapors expand in the tank. When the tank pressure increases, it expels fuel vapors. These vapors are the light 'ends' of the gasoline and the most volatile, so it is important to trap them in the charcoal before they reach the atmosphere.

The canister is connected to the top of the fuel tank, so only vapors can reach the charcoal. If liquid fuel were to enter the canister, it could degrade the carbon over time. Liquid would also clog vapor flow through the lines. For this reason vehicle manufacturers have developed various vapor separators and installed them where the vapor line enters the tank. Another function of the separator is to prevent fuel from spilling if the vehicle should roll over in an accident.

The canister is also part of the purge system and is usually connected to the intake manifold with an inline vacuum or solenoid valve to control flow. More sophisticated systems vary the rate of purge using a duty-cycle or pulse-width modulated solenoid. The PCM controls the solenoid, using the oxygen sensor signal or the adaptive strategy pulse width to determine when to increase or decrease the purge-vapor flow.

Although this system has evolved considerably since its introduction, two problems remain. The first concerns the evaporation of hydrocarbons out the canister vent. While the canister should trap *all* fuel vapors, there are times when it is unable to fulfill this task. During certain conditions, the canister can enter a condition called *breakthrough*. Breakthrough occurs when fuel vapors condense and saturate the activated charcoal beyond its capacity to adsorb. At this point hydrocarbons evaporate through the canister vent and into the atmosphere. Even current OBD-II systems are unable to detect or address this condition.

The second problem concerns the evaporation of fuel during refueling. This is solved on newer cars with onboard fuel vapor recovery systems. The idea is to gather the vapors emitted at the fuel nozzle to filler neck connection and store them to be burned at a later time.

The Plot Thickens

The operation of a basic evaporative system may sound simple, but it can become a very complex and frustrating system to diagnose when OBD-II monitors are added. Take comfort in knowing that automotive engineers have struggled with the evaporative leak monitors to make them robust enough to survive any condition the car may encounter. Let's take a hypothetical look at how an OBD-II monitor might find a leak.

Automakers began to phase in OBD-II computer systems in 1994 and by 1996 at least some of these systems were monitoring evaporative leaks. The regulations mandated the ability to detect a leak equivalent to an opening of 0.40 inches (1 mm) or larger, starting with the 1996 model year. This wasn't as easy as first thought, so many vehicle manufacturers received an exemption that allowed them to wait until the 1997 or 1998 model year before attaining the 0.40 inch standard. Regulations also state that the manufacturer must monitor the purge system for flow and turn on the MIL if the system monitor detects no flow.

OBD-II regulations allow for two methods of monitoring leaks: pressure or vacuum. It seems vacuum is more popular. This method is relatively simple in concept, although complicated in application. The approach is to apply vacuum to the fuel tank, then see whether it holds. Vacuum can be applied by opening the purge valve while closing the canister vent. This method tests the entire system, including the tank, canister, gas cap and lines from the purge valve to the tank. A fuel pressure sensor is usually installed on the fuel tank, and this signal is sent to the PCM to monitor tank pressure or vacuum. If the vacuum holds for a predetermined time, the monitor considers the system intact.

The second method is very similar, but it uses pressure instead of vacuum. At least one manufacturer uses a pump to apply pressure to the system, then watches the pressure sensor to see whether the pressure holds. Toyota used the pressure method for OBD-II systems on model years prior to 2000. These systems don't incorporate a pump for the pressure test. Instead, the system takes advantage of the natural pressure buildup caused by heat from the environment and the exhaust system and of the fuel's inclination to volatilize.

It doesn't matter which system is used, as long as the results are an effective evaporative emissions monitor. In fact, many of the same operational problems exist for both methods. Factors that can affect fuel leak detection include fuel volatility, fuel tank liquid level, tank size, ambient temperature and driving conditions.

All of these conditions contributed to the delayed introduction of evaporative system leak monitoring on some models until after the 1996 model year. The leak monitor is a very delicate measurement because it uses such a small vacuum or pressure to find a very small leak. Most pressure or vacuum systems use less than 20 inches of water (14 inches of water = 1 psi). Attempting to make such a delicate measurement can cause problems if the conditions are not ideal.

Ambient temperature is a major factor when testing for leaks. Fuel that is too hot produces more vapors, which increases pressure. This increase in pressure causes a vacuum-type monitor to see a leak while a pressure-type monitor may miss the same leak. If the ambient temperature is too cold, it may freeze moisture in the lines, which will also cause false-pass or -fail situations. Fuel volatility also affects pressure increases or decreases. The Reid vapor pressure of the fuel is not a measured parameter and must be assumed as 'standard.' The engineers have attempted to minimize the potential for leak detection problems by keeping the enable criteria for the test procedure within a narrow ambient temperature window.

The surface area of the fuel is important as well. The more surface area exposed, the more vapor produced. Due to their larger surface area, the monitor accuracy drops as fuel tanks approach 25 gallons. Fuel slosh is still another factor in maintaining proper pressure. As fuel splashes onto the warm sides of the tank, the heat vaporizes some fuel, which increases tank pressure. If the driver is accelerating, turning or passing, this can cause the fuel to slosh and tumble in the tank, resulting in yet another false-pass or -fail.

Most manufacturers have done a good job of factoring these conditions into the system strategy. We shouldn't have to worry about them when we are diagnosing a evaporative fault code. But it is important to know how these conditions may affect your diagnosis if you are trying to get the monitor to run. It may be impossible to get a monitor to say READY for the evaporative system if you have a condition outside the strategy window.

For example, we created an evaporative system 'leak' on a 1996 RAV4 by disconnecting and plugging the line to the fuel pressure sensor (so no fuel could escape from the line). With the sensor disconnected, the sensor was unable to measure tank pressure and would only sense ambient atmospheric pressure. We drove the car for four weeks and the evaporative monitor never ran to completion.

When we started running our test, we did not have the information necessary to understand what it takes to get the monitor to run. After talking with sources at Toyota, we learned that not all of the parameters were met. There is also the possibility that the monitor ran but did not complete due to the artificial failure we had introduced.

According to Toyota, the enable criteria for the evaporative monitor are as follows:

- Coolant and air temperature must be within 12 degrees F of each other at startup. The ambient temperature must be between 40 and 100 degrees F and should ideally be below 95 degrees F.
- If these conditions are met, the vehicle must then be driven according to the "Los Angeles Number 4 Drive Cycle." Only then will the monitor run.
- The monitor will run in under 20 minutes and may complete in 12–15 minutes if no problems are detected. If a problem is detected, it may take longer.
- Although a fuel level input is not used on Toyota models, there is software in place to judge fuel sloshing, and this condition may suspend the monitor.
- The vehicle can't be shut off during this test, or the monitor will abort until the next cool-down cycle.
- If the monitor passes the first trip test, it will set the readiness flag to COMPLETE. Two failures in sequential trips are necessary to set the MIL status to ON and store a code.

The evaporative monitor can be difficult to run on many cars. As we approach the year 2001, this may become an issue for some technicians, as the EPA has instructed certain states to begin checking for OBD-II codes and readiness monitors.

Toyota Evap System History

Now that we've covered the overall *how's* and *why's* of OBD-II evaporative emissions monitoring, let's delve deeper into how Toyota controls and monitors its evaporative systems. Toyota OBD-II evaporative systems can be divided into two categories: early and late systems. This month we will cover the early system and follow up in a subsequent issue with the late system.

The early Toyota evaporative emissions system is fairly simple. It uses two solenoids, a charcoal canister, fuel tank, gas cap and vapor separator or rollover valve. A 1996 RAV4 serves as our 'mule' to illustrate this system. The method used for leak detection involves monitoring the normal pressure that builds in the fuel tank. Environmental conditions, including the routing of the exhaust system, cause this increase in pressure. The RAV4 system is similar to all Toyota systems built prior to the 2000 model year.

Our RAV4's charcoal canister is attached to the left front fenderwell, in the engine compartment (**Figure 1**). The Toyota canister design is different from other manufacturers', as it plays an integral role in allowing the pressure to increase so the monitor can run. It does this by opening an air valve in the fresh-air side of the canister. This allows pressure to build in the tank. There are two of these air valve assemblies at the top of the canister, to control flow through the canister, to allow the tank to vent, as well as to purge the vapor.

Two electrically controlled vacuum solenoid valves (VSV's) are used to control the system. VSV's come in two flavors: two- and three-port, both used on this vehicle. On the RAV4, a two-port VSV is used as a purge control valve. It is controlled by the PCM and is normally closed. The PCM opens the solenoid to purge fuel vapors from the canister as conditions permit.

The second VSV is a PCM controlled, three-port that connects the vapor pressure (VP) sensor to the system. On the Toyota system, pressure is used to check the fuel tank, vapor lines, fuel cap and only a section of the canister. A hose could be off the purge VSV, but that would not set a leak code.

The regulations state that the system must be monitored for leaks from the purge valve up to and including the fuel tank. Toyota checks the purge VSV to the canister by monitoring the pressure sensor when the VP VSV is OFF. If it does not see a pressure drop when the purge VSV opens, it will set a code P0441. When the purge VSV closes, the PCM checks the VP to see whether low pressure holds. Code P0441 does not indicate a leak to the atmosphere. Rather, Toyota uses this procedure to verify the flow and integrity of the system.

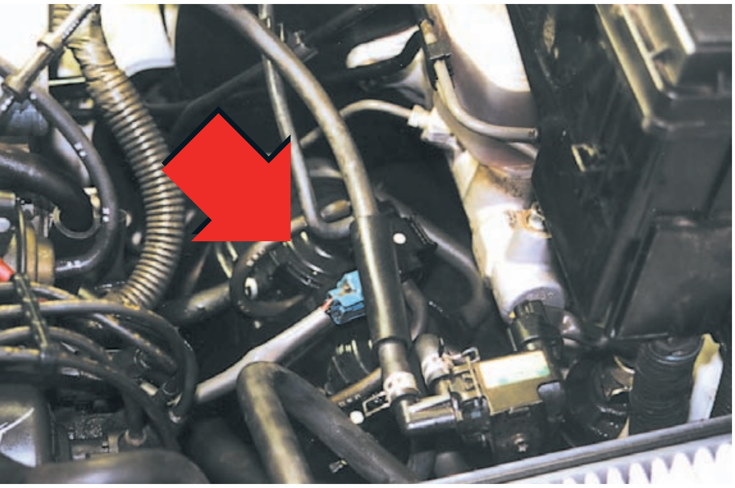

Figure 1: *The RAV4 canister is mounted in the engine compartment, behind the air cleaner assembly. Other models mount the canister under the car near the fuel tank or in other places.*

Figure 2: *Most manufacturers mount the pressure sensor on the fuel tank. Toyota mounts the sensor near the charcoal canister.*

The pressure sensor is on the firewall and connects to the canister via a vacuum line and VSV. This differs considerably from some other manufacturers' designs with the sensor on the fuel tank. The pressure sensor is used for two functions: to monitor for leaks as well as to check the system for vapor flow. This eliminates the need for two separate sensors in the system (**Figure 2**).

Go With The Flow

Tracing the flow through the canister is no easy job. Let's map it out, using **Figures 3 and 4** *(page 14)* as a guide:

- Flow is directed using the pressure differentials caused by tank and purge flow across the air valves.
- Flow and pressure are controlled with VSV's, according to operating conditions.
- The vapor pressure (VP) sensor VSV allows pressure from the tank to apply to the VP sensor when the VSV is ON.
- When the VSV is OFF, the VP sensor monitors the pressure of the canister.
- If VSV OFF pressure equals atmospheric, a code P0440 is set.
- Pressure and flow are not controlled by this VSV, except to direct the pressure to the VP sensor.
- If the pressure differential is low enough (below about 1/3 PSI), the tank, lines and air valve portion of the canister are isolated from the rest of the system.
- If pressure increases, the air valve will open and allow the fuel tank to vent through the canister.
- The VP sensor will still see pressure, with the VP sensor VSV ON, as the air valve operates like a regulator.
- The flow through the canister is directed through the vent side air valve, after passing through the activated charcoal.

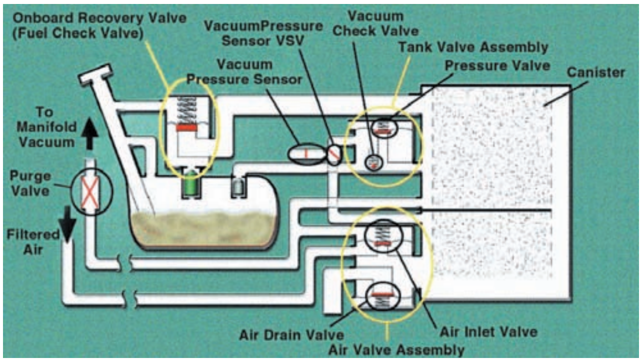

Figure 3: *This diagram shows the components of an early OBD-II Toyota evaporative system. This includes the On Board Vapor Recovery system, which was introduced on some early systems for the 1998 model. All line art illustrations courtesy of Toyota University.*

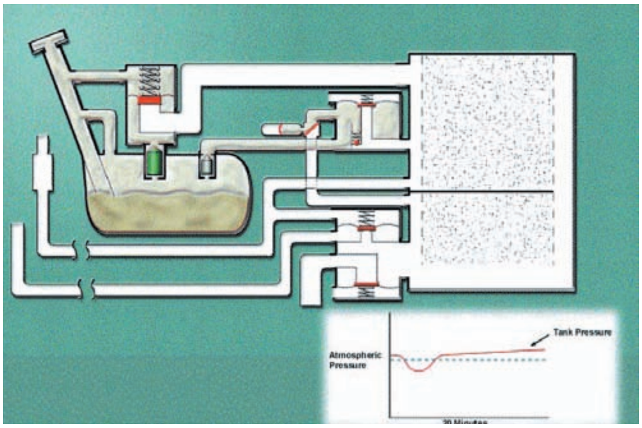

Figure 4: *With the VP sensor VSV turned ON by the PCM and tank pressure present, the VP sensor monitors the tank for a leak.*

- As the fuel cools, pressure in the tank drops; the vacuum check valve opens and allows flow through the canister and into the tank.
- The fuel cap can also allow this flow if the pressure differential is great enough.
- The purge VSV is opened by the PCM when the engine has reached the following conditions: engine operating in closed loop and ECT above 125 degrees F. A duty-cycle controlled VSV controls flow volume according to engine operating conditions. (**Figure 5**).
- When the purge VSV opens, it applies a lower pressure to the canister and to the vent side air valve. This allows the vent air valve to pass fresh air into the canister via the filtered air intake line.
- In addition, if the VP sensor VSV is OFF, the VP sensor sees the lower pressure in the purge flow line. No pressure drop here causes a code P0441.
- When the purge VSV closes, the lower pressure equalizes in the canister, and the differential across the vent air valve is equal.
- The valve shuts, creating a lower pressure area in the canister.
- This lower pressure area is monitored by the VP sensor. If the pressure change is large enough, a code P0440 is set, indicating a leak in the canister (**Figure 6**).

Diagnostic Trouble Codes

OBD-II has standardized diagnostic trouble codes (DTC's) for automotive computers. Powertrain codes always start with the letter P; chassis codes with a C; and body codes with a B. The second digit is either a 1 (for a manufacturer-specific code) or a 0 (for a generic code). The third digit represents the specific system area. The evaporative system is emission-related, so codes for this system will always have a 4 as the third digit. The last two digits are used to describe the problem in more detail.

Early Toyota evaporative monitors use at least two codes (P0440 and P0450) to identify problems in the tank-side leak monitoring system. P0450 indicates a problem with the pressure sensor, and P0440 indicates a leak. Both codes use two-trip detection logic, so they won't turn on the MIL unless the fault occurs during two sequential drive cycles. However, a pending code will set on the first failed drive cycle.

Code P0450 sets if the vapor pressure sensor indicates a partial vacuum lower than 1.0 in Hg or equal to or greater than 0.4 in Hg for more than 7 seconds after the engine has run for at least 10 seconds.

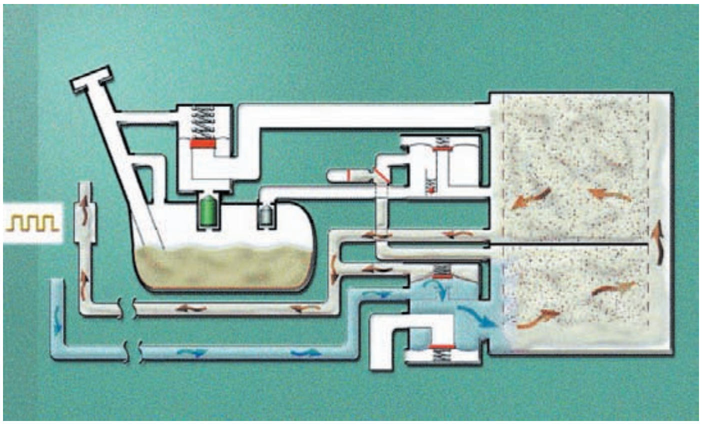

Figure 5: *As the purge VSV is turned ON by the PCM, fresh air is drawn through the filtered air vent and into the canister. The fuel vapors are removed from the canister and sent to the intake manifold.*

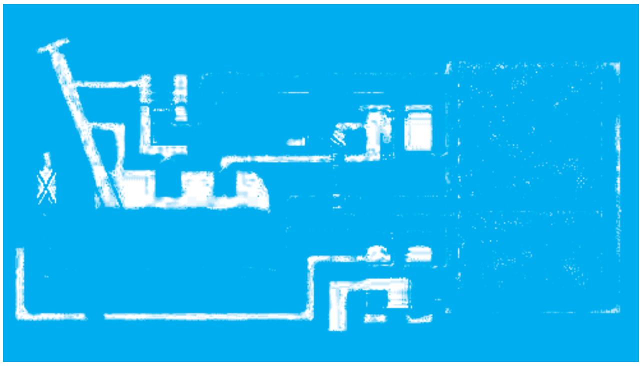

Figure 6: *When the VP sensor VSV is OFF, the system can monitor the canister and purge lines for leaks. This is done after the purge VSV is turned OFF.*

Code P0440 sets if fuel tank pressure equals atmospheric pressure after the vehicle is driven for 20 minutes.

A third code, P0441, is used as a flow code, but Toyota does something a little different here. As we have said, P0441 can also indicate a leak in the canister or the lines to the purge VSV.

Problems with these first generation Toyota OBD-II evaporative systems frequently center around faulty canisters. This sets a code P0441. P0441 is set when no purge flow is detected and usually occurs after the canister charcoal migrates out of the canister and into the purge VSV. Replacing the VSV will only temporarily solve the problem until the next dose of charcoal moves. The complete fix can be found in Toyota TSB EG003-98, and includes replacement of the charcoal canister.

This concludes our discussion of the early evaporative system on Toyota cars and light trucks from 1996 through 1999. The system design was changed for model year 2000, and onboard vapor recovery was also added. We will cover that system next time. ■

—By Randy Bernklau

FTP Measurement

To get a better understanding of OBD-II and to learn why these systems are designed the way they are, we need to understand the Federal Test Procedure (FTP) test and emission standards. Before we can do this, we need to understand the actual measurements used for modern cut-points, called grams-per-mile.

Many technicians are familiar with the concentration numbers displayed on the typical exhaust gas analyzers used in a shop environment. However, these numbers do not properly represent the actual pollution level of the vehicle. For example, a four cylinder engine that shows a reading of 1 percent carbon monoxide on a conventional five-gas exhaust analyzer does not produce the same amount of actual pollutants as a big V8 showing the same concentration percentages on the same five-gas analyzer.

Grams-per-mile is a more accurate measurement that represents *actual* emission levels. The grams in the GPM reading is the actual weight of the particular gas being measured, compared with the actual number of miles driven. Another measurement used is grams-per-hour (GPH). This is used to measure evaporative emissions when the car is at rest.

Grams-per-mile is derived from a concentration measurement that is taken while the car is driven on a dynamometer. The analyzer uses a constant volume sampler to compute the actual weight of the emissions released by the vehicle during the test.

Still confused? Several years ago a good friend of mine explained grams per mile this way. A typical aspirin tablet is 500 milligrams. If a car is emitting 2 grams of hydrocarbons per mile, this is the same as throwing four aspirin tablets worth of gasoline out the window for every mile you drive. New vehicle tailpipe emissions are typically less than 1/8 of a gram of hydrocarbons for each mile driven.