DIAGNOSING FUEL DELIVERY PROBLEMS

No fuel, no go. It's that simple. Internal combustion engines require a fuel delivery system that can not only supply fuel to the engine but also mix it with just the right amount of air to create an explosive mixture that burns efficiently and cleanly.

The air/fuel ratio varies and depends on the operating conditions at the moment. When an engine is warm and running under light load, an air/fuel mixture of about 14.7 parts air to 1 part fuel (14.7:1 by weight) provides the best combination of power, fuel economy and emissions.

But a cold engine won't start with an air/fuel mixture of 14.7:1. A cold engine needs a lot more fuel to get the fire light, as much a two or three times as much fuel depending on the temperature. This is called a "rich" mixture because the relative proportion of fuel to air is higher than the normal or "stoichiometric" ratio or 14.7:1.

Rich fuel mixtures make more power (12:1 is considered optimum) but also increase fuel consumption and pollution (namely carbon monoxide emissions). "Lean" fuel mixtures, on the other hand, improve fuel economy and emissions but reduce power. If the air/fuel mixture goes too lean (beyond 18:1), the mixture may not ignite causing a condition called "lean misfire." The result can be rough idle, loss of power and increased hydrocarbon (HC) emissions because the fuel does not ignite and just blows right through the engine. Extremely lean fuel mixtures can also burn spark plugs and pistons, and contribute to engine-damaging conditions such as detonation and preignition.

Overly lean fuel mixtures can be caused by vacuum leaks in the intake manifold, an EGR valve that fails to close, dirty fuel injectors and low fuel pressure. Overly rich fuel conditions, on the other hand, can be caused by excessive fuel pressure, restrictions in the air intake such as a dirty air filter, or a dead oxygen sensor.

COLD STARTING

The fuel delivery system changes the air/fuel mixture as the engine's needs change. When a cold engine is first started, the fuel delivery system supplies extra fuel so the engine will start. On older vehicles with carburetors, this task was accomplished by the "choke." The choke blocked off air flowing into the carburetor so more gas would be pulled into the engine when it was cranked. The choke would be closed when the engine was closed and open when it was hot. The choke was also attached to a cam that would increase the idle speed when the choke was closed.

Fuel injected engines do not have a carburetor or a choke, so on some engines the extra fuel that's needed for starting is provided by a special "cold start injector." A relay and a timer operate the cold start injector for a brief time when the engine is first cranked, then turn it off when the extra fuel is no longer needed.

On newer engines, the cold start injector has been replaced with an improved control strategy. The "Powertrain Control Module" (PCM) looks at the "coolant temperature sensor" to determine if the engine is hot or cold. If the engine is cold and needs extra fuel enrichment to start, the PCM increases the on-time of the fuel injector pulses to supply more fuel to the engine.

As the engine warms up, less fuel is needed to keep it idling. On older carbureted engines, a heat-sensitive bimetal spring inside the automatic choke slowly opened the choke and decreased the idle speed. With electronic fuel injection (EFI), the PCM monitors engine temperature and gradually leans the mixture as the engine warms up. The PCM also looks at the signal from the "oxygen sensor" (O2) to monitor the air/fuel ratio and makes adjustments as needed.

ALWAYS CHANGING

The engine's fuel requirements change with speed and load. To go faster, the engine needs more air and fuel. Opening the throttle increases air flow, and with it fuel delivery. The ratio doesn't have to change, but the quantity does. A 350 cubic inch V8 engine that needs less than 75 cubic feet of air per minute (CFM) at idle may suck as much as 500 CFM at wide open throttle at 5,000 RPM.
On older carbureted engines, opening the throttle increased air flow through the venturis. This allowed intake vacuum to pull more fuel through the jets into the engine. On engines with electronic fuel injection, opening the throttle still allows more air into the engine. But vacuum does not suck more fuel into the engine. With EFI, fuel is sprayed into the intake ports under pressure through the fuel injectors. If more fuel is needed, the PCM commands the injectors to provide it.

One of the advantages of fuel injection is that it improves fuel atomization for crisper throttle response, better performance, fuel economy and emissions. It also makes cold starting easier and improves idle quality while the engine is warming up. But it's also a lot more complicated.

The PCM uses a "throttle position sensor" (TPS) to detect changes in the throttle opening, and an "airflow sensor" (hot wire or filament mass airflow sensor or a vane type airflow sensor) and/or a "manifold absolute pressure" (MAP) sensor to monitor changes in airflow and intake vacuum. The PCM then calculates how much fuel is needed to maintain the desired air/fuel mixture and increases the injector pulse width accordingly to supply the needed fuel.

When the engine is under load, it needs a slightly richer mixture to develop peak power. Likewise, when it is loafing along or coasting, the fuel mixture can be leaned to reduce fuel consumption and improve fuel economy. On older carbureted engines, this fine tuning of the air/fuel mixture as engine load changed was accomplished with a "power valve." On engines with EFI, the same thing is accomplished mathematically by the PCM using inputs from its various sensors.

The same goes for momentary fuel enrichment when accelerating. When the throttle is quickly mashed to the floor, the engine sucks in a big gulp of air. This must be offset almost instantly by an extra dose of fuel otherwise the engine will stumble and hesitate. On older carbureted engines, the "accelerator pump" provided the extra squirt of fuel when the throttle opened. On newer engines with EFI, the computer simply commands the injectors to spray more fuel.

**FUEL FEEDBACK LOOP**

Something else you may not know about late model fuel delivery systems is that the fuel mixture is constantly changing even when operating conditions are not. To operate at peak efficiency, the "catalytic converter" in the exhaust system requires an air/fuel mixture that is constantly changing back and forth from rich to lean. The converter acts like an afterburner to reburn and oxidize hydrocarbons and carbon monoxide in the exhaust (it also reduces levels of oxides of nitrogen (NOX) in the exhaust). But to oxidize the pollutants, it needs extra oxygen. The oxygen can be supplied by an air pump, or by alternating the air/fuel mixture from rich to lean and back again.

This job, along with the fine tuning of the air/fuel mixture, is handled by the PCM "feedback fuel control loop." The PCM looks at the signal from the oxygen sensor mounted in the exhaust manifold to determine if the fuel mixture is rich or lean. When there is less oxygen in the exhaust, the output voltage of the O2 sensor jumps to its maximum output of about 0.8 to 0.9 volts indicating a rich mixture. The PCM then commands the mixture to go lean. When the level of unburned oxygen in the exhaust goes up, the O2 sensor's output drops to 0.3 volts or less indicating a lean mixture. The PCM then commands the fuel mixture to go rich. The rapid flip-flop back and forth from rich to lean results in an overall balanced air/fuel mixture that keeps the converter working at peak efficiency.

Most oxygen sensors, therefore, are essentially lean/rich indicators that switch back and forth when the fuel mixture changes. On some of the newest vehicles, a new type of "wide band" oxygen sensor is now being used that measures the actual air/fuel ratio. One advantage of this type of sensor is that it can measure extremely lean air/fuel ratios, which may be used when decelerating to reduce fuel consumption and emissions.

The condition of the oxygen sensor is important because it has such an influence on the fuel delivery system and engine performance. A good O2 sensor responds quickly to changes in the air/fuel ratio. If the O2 sensor has been contaminated with phosphorus from oil leaking past the rings or valve guides, or silicone from an internal coolant leak, or lead (which is no longer used in gasoline), it can become sluggish and unresponsive. The result can be increased fuel consumption and emissions. For this reason, some experts recommend replacing high mileage O2 sensors to restore like-new engine performance.
TYPES OF EFI SYSTEMS

Fuel injection has been used on almost all vehicles since the mid-1980s. Some of the older applications are "Throttle Body Injection" (TBI) systems with one or two injectors mounted in a single throttle body. Most, though, are "Multiport Fuel Injection" (MFI) systems with individual injectors for each of the engine's cylinders. One other variation is General Motors "Central Point Injection" (CPI) that uses a single centrally-located master injector to route fuel to mechanical injectors at each cylinder.

All electronic fuel injectors work essentially the same. An electrically-operated solenoid in the top of the injector pulls open a pintle or ball valve so pressurized fuel can spray out of the injector nozzle or orifice. The flow characteristics, spray pattern and calibration of the injectors is matched to the engine application, so replacement injectors must be the same as the original -- unless somebody is modifying an engine and they need higher flow injectors to boost power.

On some engines, all the injectors are pulsed simultaneously once every engine revolution. On many newer engines, each injector is pulsed individually in a sequence that corresponds to the firing order of the spark plugs ("Sequential Fuel Injection" or SFI). This allows more rapid changes in the fuel mixture for better throttle response, performance and emissions.

Fuel pressure is provided by a high pressure electric pump which is usually mounted inside the fuel tank. Fuel pressure is regulated by a "fuel pressure regulator" mounted on the injector fuel supply rail on the engine, or at the pump in the tank in case of "returnless" EFI systems. The latter have no fuel return line from the engine back to the fuel tank to recirculate fuel that bypasses the regulator. It's all done in the tank.

EFI PROBLEMS

Fuel problems usually fall into one of three categories: injector-related, pump-related or sensor-related. Short trip stop and go driving combined with the use of cheap gasoline that does not contain adequate levels of detergent can allow varnish deposits to build up in the injectors. "Dirty" injectors that are clogged with gunk can't provide their normal dose of fuel with each squirt. This leans out the fuel mixture and may cause hesitation, lean misfire, rough idle and surging.

Dirty injectors can often be cleaned with fuel additives, or by on-car or off-car cleaning equipment. If injectors do not respond to cleaning, the whole set may have to be replaced to restore normal performance. If only a single injector is clogged, leaking or electrically shorted or open, it can be replaced individually.

A dead fuel pump will supply no fuel to the engine and prevent the engine from running. A weak pump, on the other hand, may provide enough fuel for idle and low speed operation but starve the engine for fuel under load or at higher speeds. A pump that cannot meet pressure and volume specifications must be replaced. Sometimes a "bad" pump is still good but isn't running or is running too slowly because of a wiring or relay problem. These items should be ruled out before a pump is replaced to prevent unnecessary returns. The fuel filter and pump inlet screen should also be replaced when a new fuel pump is installed.