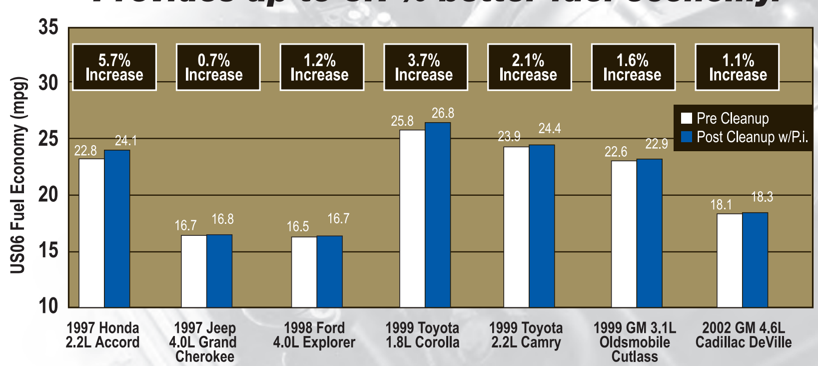
FIELD STUDY

AMSOIL
The First in Synthetics®

AMSOIL P.i.: A Study in Performance

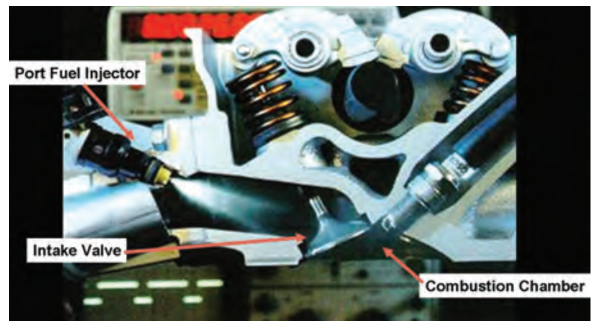
Provides up to 5.7% better fuel economy.



In response to Environmental Protection Agency (EPA) fuel economy and emissions regulations, fuel injection systems replaced carburetors in new vehicles in the 1980s. Fuel injectors allow more precise control of fuel than carburetors, improving fuel efficiency and minimizing emissions. However, in order to work efficiently, they must be kept clean. Because performance suffers as fuel injectors become dirty, the U.S. government mandated in the mid-1990s that all gasoline sold in the U.S. be formulated with a lowest additive concentration (LAC) level of detergent additives to help keep engines clean and emissions under control. However, it takes a very low level of additive to pass the tests, and most gasoline on the market contains as little as 123 parts per million (ppm) of additive.

The low levels of detergent additives in modern gasoline allow deposits to build up on critical fuel system components, and most motorists are unaware of how dirty the insides of their engines are. AMSOIL P.i. Performance Improver is an effective one-tank, total fuel system cleaner. More potent than other fuel additives on the market, P.i. effectively cleans everything the fuel touches, including both port and direct fuel injectors, intake valves and combustion chambers, in only one single tank of gasoline, removing the deposits that have built up over thousands of miles. Removing engine deposits with P.i. effectively improves fuel economy, reduces emissions, restores power, performance and acceleration, reduces octane requirements, increases engine life and reduces maintenance costs.

Port Fuel Injectors

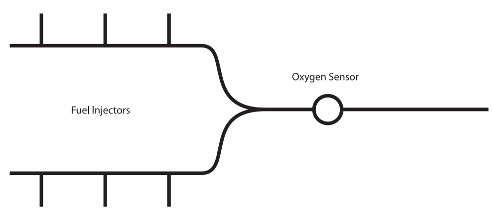


Port fuel injectors transfer liquid gasoline from the tank and spray it in a fine mist into the intake air stream, increasing surface area and allowing the gasoline to evaporate into a gaseous state as it enters the engine. There are two types of port fuel injectors: pintle and director plate.

Pintle Style Injectors

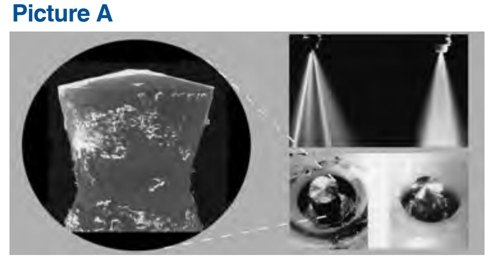
Pintle style fuel injectors feature a pintle-shaped spray tip that produces a hollow cone of spray, at least when it is clean and working properly. **Picture A** shows a greatly magnified pintle tip with bits of built-up deposits. These deposits, although they don't look like much to the naked eye, can significantly alter the spray pattern of gasoline. **Picture A**, as well as **Pictures B** and **C** (on the next page), show the spray patterns of a dirty injector and the same injector cleaned with P.i. **Picture C** shows an ideal spray pattern, a good mist with plenty of surface area for evaporation to take place. When deposits start to build up on an injector's pintle, the spray pattern looks more like **Picture B**, a steady stream of liquid gasoline. In order to burn properly, gasoline must evaporate to a gaseous form, and liquid gasoline has more difficulty evaporating. In addition, not as much fuel is delivered through a deposit-covered injector as a clean injector, leading to lean misfires in the cylinder.

Director Plate Injectors

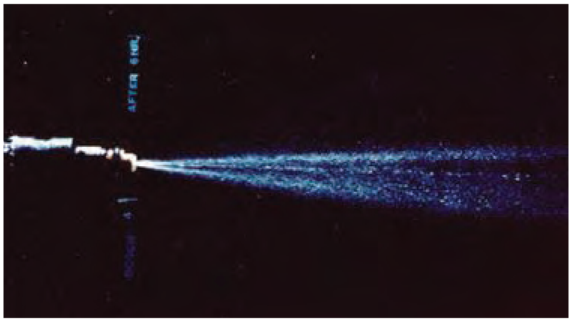


While pintle style fuel injectors were common in the 1980s, modern vehicles feature director plate injectors that control fuel flow through a simple wafer. Featuring a pre-determined number of holes, pressure drop across the wafer forms the spray of fuel through the holes. The more holes that are in the wafer, the better the fuel atomization. However, as more holes are added to a director plate design, they must be made increasingly smaller in order to maintain the pressure drop. Twelve-hole wafers are common on modern vehicles, providing optimum atomization, fuel economy and emission levels. Of course, they must be clean and functioning properly to realize these benefits. Smaller holes are more sensitive to deposit formation and, like pintle style injectors, dirty director plate injectors lead to reduced fuel spray and heavy streams of liquid gasoline that do not allow adequate evaporation, leading to reduced fuel economy, increased emissions and drivability issues. Because the holes in a 12-hole injector are about the size of a human hair, they are very sensitive to contamination, and it only takes a small amount of deposits to impede the flow of fuel.

Picture A

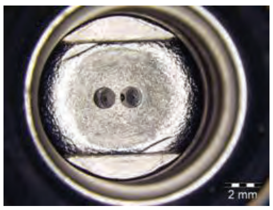


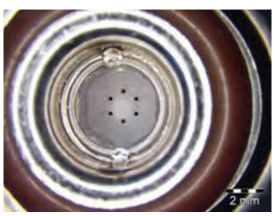
The spray pattern on the right shows the P.i.-treated injector.

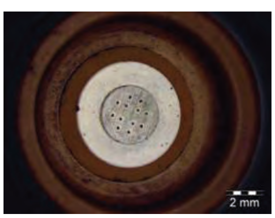


Picture B - Injector spray pattern **before** P.i. treatment

Picture C - Injector spray pattern **after** P.i. treatment







As more holes are added to director plate designs, they must be made increasingly smaller in order to maintain the pressure drop.

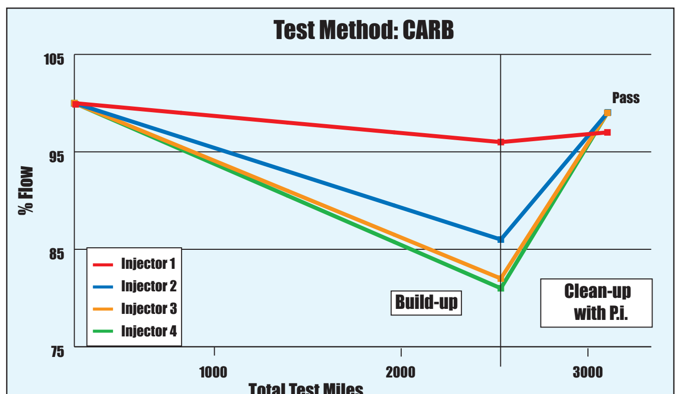
By measuring oxygen, the **oxygen sensor** in the exhaust stream is able to calculate how much gasoline the injectors are spraying, as well as the air/fuel ratio. Although vehicles are usually equipped with many fuel injectors (one per cylinder), only one oxygen sensor monitors them all. Through the oxygen sensor, the computer is able to determine if the engine is receiving the right amount of fuel. Deposit build-up on the injectors reduces the fuel flow. When the computer determines that the engine is not receiving enough fuel, it increases fuel flow from all the injectors in the fuel system. Although this solution would work well if all the injectors lost fuel flow at the same rate, injectors almost always plug at different rates based upon their operating temperatures (inboard cylinders typically run hotter) and individual manufacturing tolerances.

Port fuel injector deposits have a significant impact on fuel economy and emissions because they plug injectors at uneven rates, and the engine cannot compensate for individual cylinders. For example, a four-cylinder engine could have two plugged injectors, while the other two may only be mildly plugged or not plugged at all. The oxygen sensor indicates to the computer that the engine is not receiving enough fuel, so it increases the fuel supply to all four cylinders. Now the two injectors that were plugged are providing more fuel, but it still may not be enough, while the two injectors that weren't plugged are providing more fuel than necessary. As a result, it creates a situation where two cylinders are running rich and the other two are running lean. Removing port fuel injector deposits allows the engine to operate as it was designed, improving fuel economy, lowering emissions and contributing to improved drivability (reduced stumbling, stalling, hesitation and rough idle) and increased power.

Port Fuel Injector Deposit Clean-Up Test

The ASTM D5598 Injector Clean-Up PFI Test was performed to test the fuel injector cleaning power of AMSOIL P.i. Performance Improver. Starting with a new, clean four-cylinder 2.2L Chrysler engine (an engine particularly sensitive to injector deposits), the car was driven and allowed to build up deposits for 2,728 miles on normal gasoline. Afterwards, deposit levels and injector flow rates were measured. The injectors did not develop deposits at the same rate, as two of the injectors were fouled >15%, one was fouled >10% and one was almost perfectly clean. After the measurements were recorded, the injectors were placed back in the car and the car was filled with a tank of gas treated with P.i. As seen in **Graph A**, all injectors returned to >95% flow after one tank of operation on P.i.

Graph A



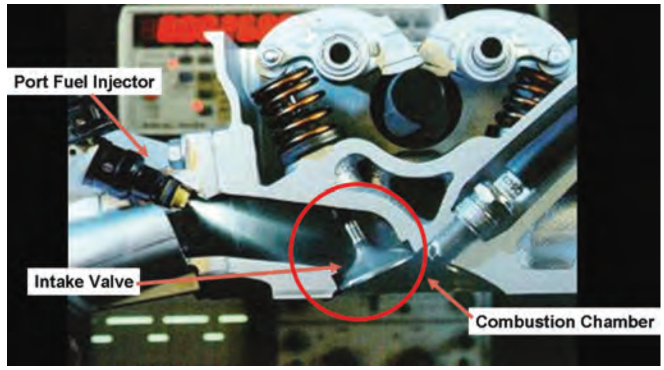
Two of the four dirty injectors tested were fouled >15% and another was fouled >10%. After one tank of operation on AMSOIL P.i., all injectors returned to >95% flow.

Whether deposits have built up over a relatively low number of miles, as in the test, or they have accumulated over 100,000 miles, P.i. effectively removes them. Because fuel injector deposits and the associated performance issues usually build up slowly over time, motorists often attribute the decreased performance to the increased age of the vehicle. When the deposits are removed in only one tank of gasoline, the performance improvement is immediate and significant.

Intake Valves

The role of the intake valve is to act as a doorway. It opens to allow fuel and air into the combustion chamber, then it closes, sealing off the combustion chamber for combustion and building up pressure in the cylinder. Because intake valves open once for every two crank revolutions, this whole process occurs very quickly. The intake valve in an engine running at 4,000 RPMs must open, allow all the fuel and air through, close and seal itself 2,000 times a minute.

Intake Valve Deposits



Intake valve deposits are present in some quantity in nearly every vehicle on the road. While some vehicles run trouble-free with a small amount of deposits, other vehicles are more sensitive to them, especially modern vehicles. The deposits tend to build up on the back side of intake valves, where they act like a hard carbon-rich sponge that absorbs fuel. The computer tells the injectors how much fuel to spray, but instead of it all entering the combustion chamber, a portion of it becomes trapped in the deposits. Thus, the combustion chamber has the correct level of oxygen, but not enough fuel, creating a lean misfire that leads to drivability issues such as stumbling, stalling and rough idle. By removing these deposits, all the fuel from the injectors is able to enter the combustion chamber.

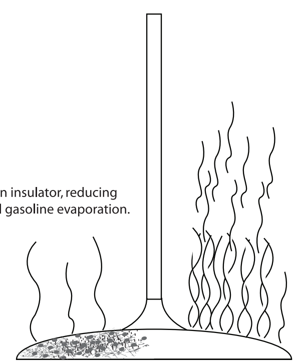
Valve sticking is another problem created by intake valve deposits. Deposits build up where the valve stem goes through the guide, causing it to stick in the guide. Although the camshaft has more than enough force to open the valve, it has trouble closing it. Modern vehicles often use lighter spring valves for fuel economy benefits, but they often don't have enough spring tension to pull the valves closed in cold temperatures. Because cold temperatures cause metals to contract and expand at different rates, tolerances get smaller, while viscous deposits grow thicker.

Picture D - Intake valve **before** P.i. treatment

Picture E - Intake valve **after** P.i. treatment

Picture D shows a dirty, deposit-covered valve, while **Picture E** shows the same valve cleaned with P.i. The dirty valve leaves an undulating surface that disrupts air flow into the cylinder and absorbs a portion of the fuel sprayed by the injector, while the clean valve contributes to improved fuel economy, lower emissions, better drivability and maximum power.

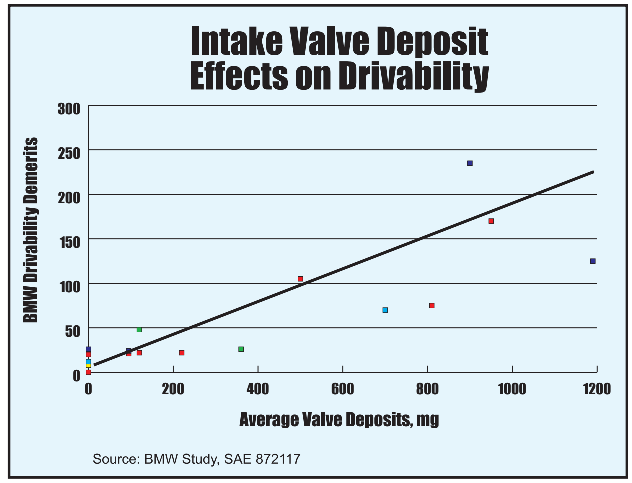
Heat must escape from the engine during combustion and post-combustion, and a great deal of it enters the intake valve. Once there, it has three ways of getting out of the engine. It can go up the stem, into the guide and out to the coolant passages; it can go through the valve seat itself, into the head and into the coolant passages or it can escape the intake valve through the surface on the back side. Any fuel on the back side of that surface evaporates and contributes to the combustion process. Because deposits act as an insulator, they block a lot of this heat transfer and force the heat to go out through the valve seat or valve stem rather than coming back to the intake track to help evaporate the gasoline.



BMW Valve Deposit Study

BMW developed a specific interest in valve deposits in the late 1980s due to drivability problems with its vehicles, including stumbling, stalling, rough idle and hesitation. A study on valve deposits showed dirty valves were the source of the problems (**Graph B** indicates that as valve deposits increased, drivability problems increased), and the company invested a great deal of time and effort searching for solutions, trying everything from polishing the valve surfaces to using ceramic-coated valves. The solution that worked was adding a cleaning additive to the gasoline.

Graph B



Intake Valve Deposit Clean-Up Test

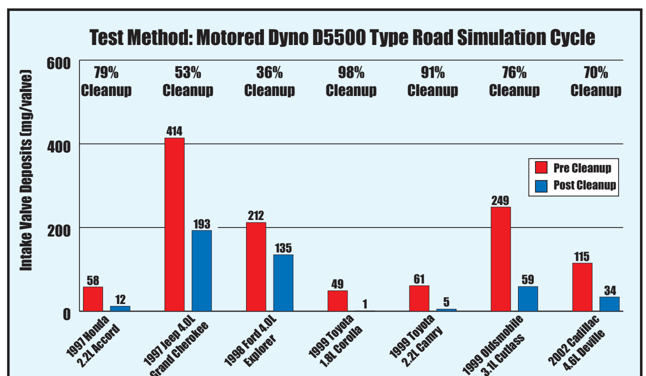
A small fleet test performed on P.i. effectively demonstrates its superior deposit-cleaning abilities. The test focused on randomly selected model year 1997 to 2002 used vehicles with between 44,000 and 94,000 miles on the odometers, and all vehicles had been operated under normal service conditions using regular gasoline available on the market.

Vehicle Model	Mileage	Vehicle Model	Mileage
1997 Honda 2.2L Accord	85,000	1999 Toyota 2.2L Camry	53,000
1997 Jeep 4.0L Grand Cherokee	94,000	1999 GM 3.1L Oldsmobile Cutlass	52,000
1998 Ford 4.0L Explorer	57,000	2002 GM 4.6L Cadillac DeVille	55,000
1999 Toyota 1.8L Corolla	44,000		

Before P.i.treatment, each vehicle was disassembled, and intake valve deposit levels were measured in a laboratory setting. Upon completion, the vehicles were put back together and filled with one tank of P.i.-treated gasoline. After running through that tank of fuel, the vehicles were brought back into the laboratory, where all the measurements were taken again.

The red bars on **Graph C** represent the pre-treatment intake valve deposit levels of the vehicles, ranging from 49 mg to 414 mg. The blue bars represent the deposit levels after P.i. treatment, showing an average 72 percent clean-up after only one tank of gasoline. Even the vehicles with minimal pre-treatment deposit levels cleaned up very well, showing an average 89 percent clean-up, with the Toyota Corolla showing 98 percent deposit clean-up.

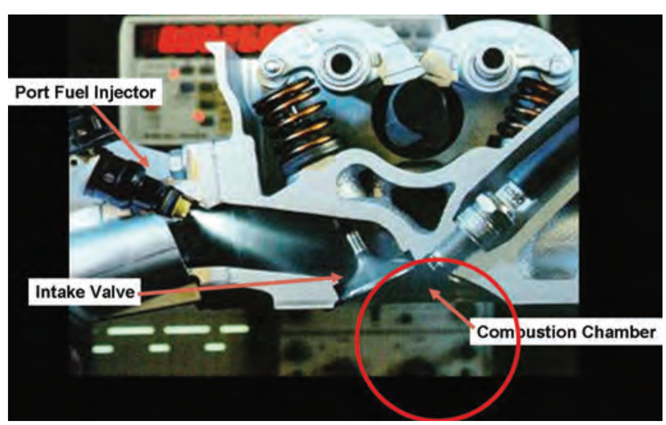
Graph C



AMSOIL P.i. averaged 72% intake valve deposit cleanup across a wide range of engine types and sizes, with two cars cleaning up greater than 90%.

Combustion Chambers

The combustion chamber is where fuel combustion takes place, and it is both the hottest location in the engine and the most difficult location to clean of deposits. Spark timing is very important in gasoline engines. Combustion must be timed so the fire develops maximum pressure once the piston has reached its peak. The role of the spark plugs is to start the fire and control the timing.



Combustion Chamber Deposits

High levels of combustion chamber deposits can negatively affect this process. Like intake valve deposits, combustion chamber deposits are present in some quantity in nearly every vehicle on the road. When allowed to accumulate, they resemble mountains with peaks and valleys. Acting as insulators that hold heat, the peaks can become hot enough to act as a secondary ignition source, igniting and creating two combustion fronts (one from the spark plug and one from the secondary ignition source).

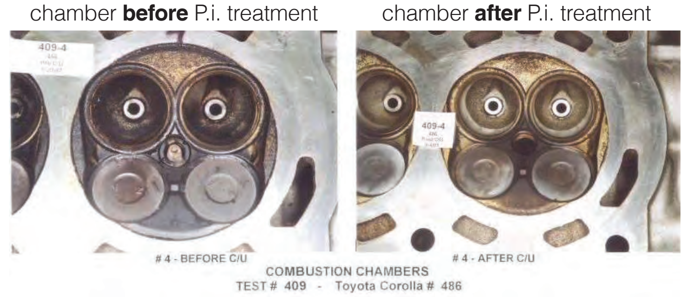
The two combustion fronts collide and bounce back and forth in the cylinder as a pressure wave, creating a knocking or pinging sound as the pressure wave hits the sides of the cylinder and leads to engine damage, including broken pistons and rings. There are two ways to remedy the problem. The first is use of a higher octane gasoline that resists ignition in the presence of the secondary ignition source (octane number requirement increase). The second remedy is to remove the secondary ignition source by removing the deposits. Removal of the secondary ignition source eliminates the need for higher octane gasoline, saving fuel expenses by allowing motorists to switch to less expensive lower octane gasoline.

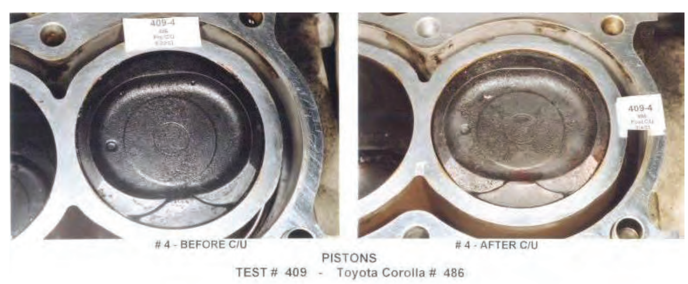
Combustion chamber deposits also create a problem called combustion chamber deposit interference. In order to meet emission standards, many modern vehicles are designed to burn everything in the combustion chamber. To do so, the outside edges of the pistons are higher than the centers so that during the end of the combustion stroke, they naturally “squish” everything back to the center. Unburned material around the outside edges gets pushed back toward the flame. Because this design causes the outside piston to come very close to the cylinder head, large enough layers of deposits on both the cylinder head and piston top in an engine with tight tolerances can cause the piston to physically hit the cylinder head, creating a loud metallic banging sound, a problem particularly evident at cold startup.

A third problem attributed to combustion chamber deposits is flaking. Combustion chamber deposits are usually the driest of engine deposits due to the hot environments in the combustion chamber, and they are very susceptible to humidity. When humidity enters the cylinder, it causes the deposits to flake, come off in large chunks and exit the exhaust valve. The problem is that not all the deposits make it past the exhaust valve. Some remain on the valve seat when the valve closes, holding the exhaust valve open slightly and leading to lost compression, difficult starting, rough idle, increased hydrocarbon emissions and a possible burned exhaust valve. To avoid this problem, it is necessary to clean combustion chamber deposits, ensuring they don’t flake off and cause problems.

Picture F - Combustion chamber **before** P.i. treatment

Picture H - Combustion chamber **after** P.i. treatment





Picture G - Piston **before** P.i. treatment

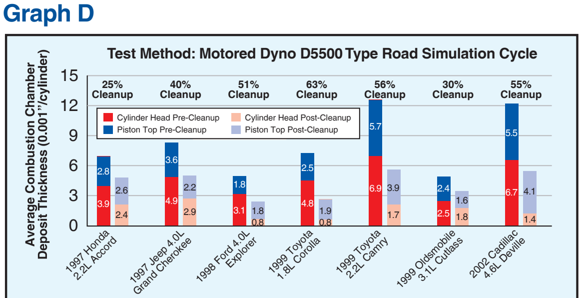
Picture I - Piston **after** P.i. treatment

Pictures F and **G** show a dirty, deposit-covered combustion chamber and piston, while **Pictures H** and **I** show the same combustion chamber and piston cleaned with P.i.

Combustion Chamber Deposit Clean-Up Test

The dark blue and red bars in **Graph D** indicate the piston top and cylinder deposit levels of each test vehicle prior to P.i. treatment, while the light blue and red bars indicate the deposit levels after one tank of operation on P.i.-treated gasoline. Every vehicle showed significant deposit clean-up, more than enough to remedy the octane number requirement increase, combustion chamber deposit interference and combustion chamber deposit flaking problems associated with combustion chamber deposits.

Graph D



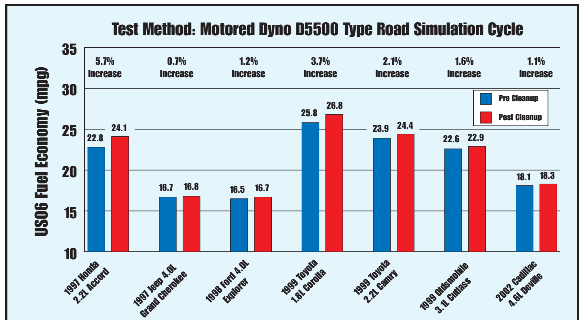
AMSOIL P.i. averaged 46% combustion chamber deposit cleanup across a wide range of engine types and sizes, with four cars cleaning up greater than 50%.

Fuel Economy Test

A primary concern for many motorists is fuel economy, and the clean-up of fuel injector, intake valve and combustion chamber deposits effectively improves a vehicle's fuel economy.

The fleet of test vehicles was put on a rolling chassis dynamometer before and after P.i. treatment, measuring each vehicle's fuel economy numbers according to the same method mandated by the federal government and used by auto manufacturers to determine vehicle fuel economy ratings. The blue bars on **Graph E** indicate pre-treatment fuel economy numbers. The red bars indicate fuel economy following one tank of operation on P.i., showing an average fuel economy improvement of more than 2 percent. Although the Honda and two Toyota vehicles had the lowest levels of deposits prior to P.i. treatment, they experienced the largest fuel economy increases after treatment, indicating that even minimal levels of deposits can have significant effects on fuel economy. In fact, many smaller engines designed for maximum fuel efficiency are among the most sensitive to deposits.

Graph E



AMSOIL P.i. provided an average fuel efficiency increase of 2.3%, with one car showing improved fuel efficiency of 5.7%.

Gasoline Direct Injection (GDI)

Gasoline direct injection (GDI) differs from port fuel injection in where the gasoline is introduced prior to combustion. In conventional port-injected fuel systems, the fuel/air mixture occurs in the intake manifold. In GDI engines, gasoline is injected directly into the combustion chamber under very high pressures, similar to how diesel engines operate. This results in better control of the air-fuel mixture, allowing greater power, torque and operating efficiency.

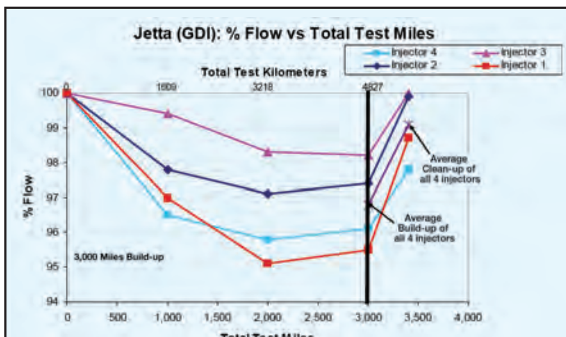
Most vehicle manufacturers are now producing vehicles incorporating GDI technology, with several reasons for their increased production. First, today's injector systems are computer-controlled and capable of delivering extremely accurate and rapid distribution of atomized gasoline. The fuel can be sprayed directly at the hottest part of the combustion chamber, which is near the spark, improving efficiency. Second, because the fuel supply is more precisely controlled, combustion can occur at leaner air-to-fuel ratios. GDI engines use a very lean mixture of 40:1 or greater during light loading conditions. The lean ratio means less fuel is burned during combustion, increasing fuel economy. Finally, when atomized fuel is injected into cylinders at high pressure, the combustion chamber temperature decreases slightly, helping further increase efficiency.

The fuel injectors in GDI engines, located directly in the combustion chamber, are exposed to elevated temperatures and pressures. This severe environment makes them more susceptible to deposits that impede the spray pattern, reducing engine efficiency. AMSOIL P.i. contains powerful detergents that clean deposits that form in combustion chambers and on fuel injectors, improving fuel economy and reducing emissions.

GDI Clean-Up Test

To determine its cleaning power, AMSOIL P.i. Performance Improver was tested in a Volkswagen Jetta with GDI fuel injection. Upon accumulating 3,000 miles, all four fuel injectors were tested to determine baseline fuel flow. As seen in **Graph F**, clean-up using P.i. increased fuel flow from 95.5% to 97.7% on the most severely-affected injector, and an average flow improvement of 2.3% (from 96.8% to 99.1%) across all four injectors was observed following use of P.i.

Graph F



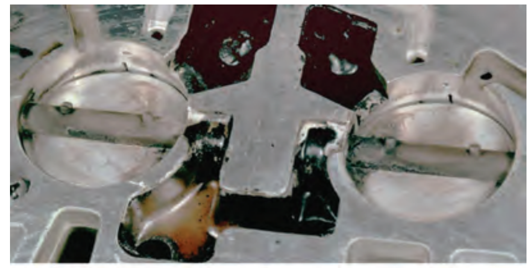
An average fuel flow improvement of 2.3% (from 96.8% to 99.1%) across all four injectors was observed following use of P.i.

Carbureted Engines

Although modern vehicle models are equipped with fuel injection systems, there are still a number of older and classic carbureted cars on the roads. P.i. works just as effectively in carburetors as it does in fuel injectors, intake valves and combustion chambers, effectively cleaning the back sides of carburetor plates, the idle air passages and all of the fuel portals just as well as it cleans the components of a fuel injection system.

Picture J shows dirty, deposit-covered carburetor plates, while **Picture K** shows the same carburetor plates cleaned with P.i.

Picture J - Carburetor plates **before** P.i. treatment



Picture K - Carburetor plates **after** P.i. treatment

Benefits of P.i. Treatment

- Increases fuel economy
  Testing yielded improvement of up to 5.7 percent
- Restores power, acceleration and drivability to “like new” condition
- Reduces emissions and helps vehicles pass emission tests
  Up to 15 percent reduction in hydrocarbon (HC) emissions (unburned fuel)
  Up to 26 percent reduction in carbon monoxide (CO) emissions (partially burned fuel)
  Up to 17 percent reduction in nitrous oxide (NOx) emissions
- Avoids necessity of expensive injector cleaning services
- Reduces engine octane requirement, saving money at the pump
- Excellent for both gasoline direct injected (GDI) and port fuel injected engines

Recommendations

Treat one full tank of gas up to 20 gallons with one bottle or up to 40 gallons with two bottles. Using more than two bottles per treatment is not recommended. Large gas tanks should only be partially filled to 40 gallons to maintain the proper concentration ratio of one bottle per every 20 gallons for best results. Treat every 4,000 miles (or 100 hours for marine, stationary and off-road gasoline-powered engines). P.i. helps pass emission tests (treat one full tank of gas, run that tank and fill up again prior to test). Safe for use with catalytic converters, oxygen sensors, oxygenated gas and 10% ethanol blended gas. Not recommended for two-cycle engines.

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