Dealer Training Series

Diesel Fuel Fundamentals

An Introduction to Diesel Fuel | Presented by AMSOIL INC.

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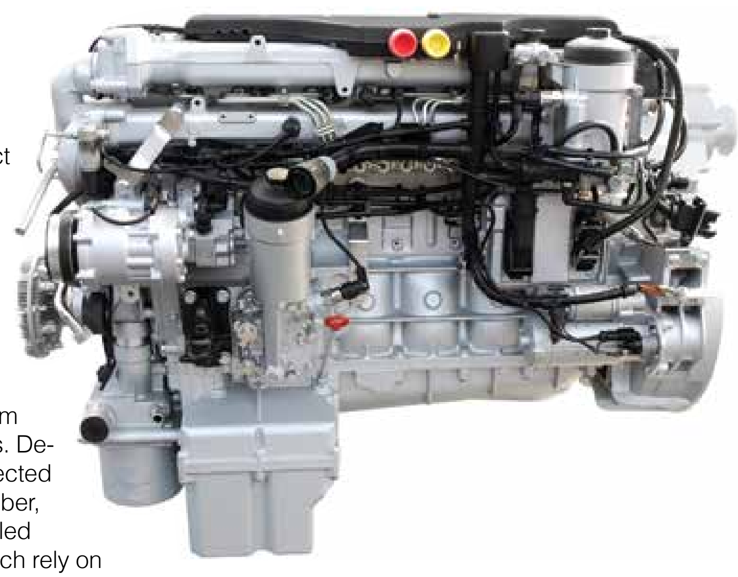
Diesel Fuel



What is Diesel Fuel?

The global industry that depends on diesel fuel was first sparked by the discovery of crude oil in 1859 in Pennsylvania. Kerosene lamp oil was the first product refined from crude, and it wasn't long before other uses were found for the crude oil by-products. In 1893, German engineer Rudolf Diesel built the first compression ignition engine, which he designed to replace the steam piston engine. Though Diesel's first engine ran on peanut oil, by 1895 he had developed a fuel we know today as diesel.

While diesel and gasoline are both manufactured from crude oil, they are used and burned in different ways. Designed to operate in diesel engines, diesel fuel is injected into hot compressed air inside the combustion chamber, where it spontaneously ignites. This is commonly called ***compression ignition***. Unlike gasoline engines, which rely on spark plugs to achieve spark ignition, diesels do not require spark plugs and typically have higher compression ratios than gasoline engines.

Diesel engines are used worldwide in numerous industries and applications. In fact, they are the most widely used engines in the marketplace. They are found in ocean freighters, railroad locomotives, garbage trucks, tractors, pick-up trucks and dozens of other applications. Big or small, diesel engines are capable of producing the high horsepower and torque needed to get the job done.

Their operation and performance, however, is dependent upon the quality of the fuel that goes into the tank. The following is an introduction to how diesel is made, its various classifications, the properties that make it such a desirable fuel and how current regulations are affecting the quality of diesel fuel that consumers purchase at the pump. It is not an exhaustive study of the topic and is intended for informational purposes only.

Oil-Refining Process

All petroleum-derived products, including diesel fuel, begin as crude oil. It is processed to refine and extract the desirable chemical structures that are used in diesel fuel, gasoline, jet fuel, kerosene, engine oil and other products. The two primary elements found in crude oil are carbon and hydrogen, which combine to form numerous compounds called ***hydrocarbons***. Crude contains a wide range of hydrocarbons of different weights, making it a poor fuel and lubricant in itself. Each of these molecular structures possesses a different set of properties that can vary widely. Crude oil also contains high levels of contaminants, such as water, sulfur, nitrogen and paraffinic (wax) material.

The ability to separate crude into its individual components, or fractional ranges, allows refiners to obtain an improved lubricant base stock and a variety of other useful products. This is done using a process called distillation, which separates the crude into fractions based on boiling range. The crude is heated until each fraction boils off as vapor and is then condensed and subjected to further processing. Though distillation increases the concentration of similar molecular structures, the final product still consists of a range of hydrocarbon structures. One could refer to this mixture as a chemical soup.

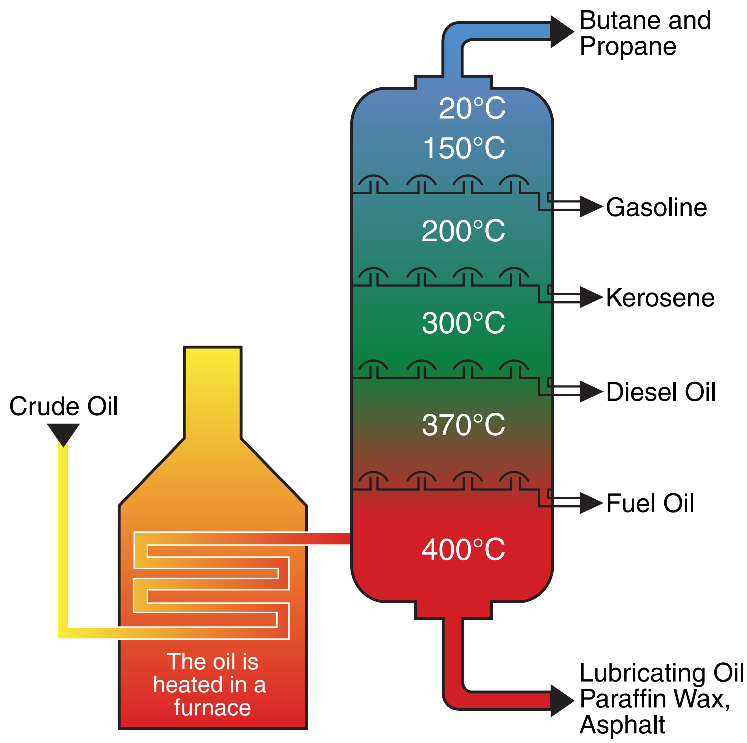
The most common type of diesel fuel is a specific fractional distillate of petroleum fuel oil also known as petro diesel. Before processing, petro diesel begins as naturally occurring crude oil. Diesel fuel is refined through an oil-refining process that uses a fractional distillation column and can be classified into three basic categories:

- **Separation** - The crude oil is heated in a furnace and the components of the oil separate into different categories based on their boiling points
- **Conversion** - A process that rearranges the molecular structures to yield valuable products
- **Upgrading** - Commonly used in reformulated fuels to remove compounds present in trace amounts that impart undesirable qualities

Distillation Towers

Crude oil contains hundreds of different types of hydrocarbons that have progressively higher boiling points, so they can be separated by distillation. Similar to early cooking methods, liquids and vapors are settled inside distillation towers, where vapors separate into fractions based on their boiling points.

The lightest fractions, such as liquefied petroleum gas (LPG) and gasoline, rise to the top and condense. Diesel and other medium-weight fractions separate out before heavy products, such as asphalt and fuel oil. Conversion — the process that rearranges the molecular structure — happens after the components are separated into their distillation towers.



Hydrocarbons

Diesel fuel is a complex mixture of petroleum-derived hydrocarbons with boiling points in the range of 150ºC to 380°C. Petroleum crude oils are composed of hydrocarbons of three major classes:

- Paraffinic
- Naphthenic (or cycloparaffinic)
- Aromatic hydrocarbons

It takes less refining to create diesel fuel, and diesel fuel has higher energy density than gasoline. On average, one gallon of diesel fuel contains approximately 147,000 BTU (British Thermal Units), while one gallon of gasoline contains 125,000 BTU.

Fuel Quality

Fuel quality has a significant effect on overall diesel performance. Fuel injection systems and engines are becoming increasingly complex. Both fuel economy and performance are highly dependent on getting the right amount of fuel into the combustion chamber in the correct physical form at the correct time. Fuel injection systems are traditionally high-maintenance items and, as a result, performance-related issues are common. Specific diesel fuel parameters can have a big effect on injector performance and resulting diesel vehicle operation.

Diesel fuels are becoming more complex, presenting new challenges for refiners. They typically include detergent and lubricity additives, conductivity and cold-flow improvers, and an increasing proportion of biofuels. As a result, it's essential for refiners to fully understand the benefits, interactions and potential harms of these different components.

Diesel fuel quality is highly variable, with large differences often occurring between, and even within, regions. Such fuel variability can create problems for owners and operators. The American Society for Testing and Materials (ASTM) D975 specification covers seven grades of diesel fuel oils suitable for various types of diesel engines. Low-grade fuels burn at a high heat value, but produce more contaminants. Higher-grade fuels have a lower heat value, but produce fewer contaminants. The requirements specified for diesel fuel oils are determined in accordance with the test methods listed in the following table.

Test Methods for Determining Diesel Fuel Grades

Flash Point	The lowest temperature at which a vapor from a diesel fuel will ignite in the air.
Cloud Point	The temperature at which the dissolved solids are no longer soluble and the wax crystals are large enough to see.
Carbon Residue	A measure of the carbon-depositing tendencies of a fuel oil when heated in a bulb under prescribed conditions. While not directly correlating with engine deposits, this property is considered an approximation.
Ash	Ash-forming materials may be present in fuel oil in two forms: abrasive solids and soluble metallic soaps. Abrasive solids contribute to engine deposits and injector, fuel pump, piston and ring wear. Soluble metallic soaps have little effect on wear, but may contribute to engine deposits.
Distillation	Distillation measures the volatility of fuel. The fuel volatility requirements depend on engine design, size, nature of speed and load variations, and starting and atmospheric conditions. For engines in services involving rapidly fluctuating loads and speeds, such as bus and truck operation, the more volatile fuels may provide best performance, particularly with respect to smoke and odor. However, best fuel economy is generally obtained from the heavier types of fuels because of their higher heat content.
Viscosity	A measure of a fluid's resistance to flow. For some engines, it is advantageous to specify a minimum viscosity because of power loss due to injection pump and injector leakage. Maximum viscosity, on the other hand, is limited by considerations involved in engine design and size, and the characteristics of the injection system.
Sulfur	An element found naturally in crude oil. Sulfur was previously allowed in diesel fuel as a natural lubricant for fuel system components. Now it is largely removed to reduce emissions from burned diesel fuel.
Copper Corrosion	A test that quantifies the corrosive nature of the fuel when exposed to soft metals. This test serves as a measure of possible difficulties with copper and brass or bronze parts of the fuel system.
Cetane Number	Diesel fuel value is measured by its cetane number, which defines the ignition quality. In the U.S. the minimum cetane requirement by the Standard Specification for Diesel Fuel Oils (ASTM D975) is 40. The ease of starting, smoke emissions, noise and overall operation depend on the cetane number. The cetane number in diesel fuel varies widely and has a large effect on performance in both warm and cool climates. It contributes significantly to noise levels, startability and power levels.
Cetane Index	An estimation based on the fuel's density and distillation range. Cetane index cannot accommodate for cetane-improver additives, and thus is used as an estimation of the base unadditized cetane number.
Lubricity	The ASTM D975 specification requires fuel to pass the High Frequency Reciprocating Rig test with a wear scar of no greater than 520 microns.

Sulfur and Lubricity

A primary difference between gasoline and diesel fuel is that diesel has natural lubricating properties due to its inherent lubricity, or slipperiness. In fact, many people refer to diesel fuel as diesel oil because it is such an oily substance. Research has found that diesel lubricity is largely provided by trace levels of naturally occurring polar compounds that form a protective layer when in contact with a metal surface. Lubricity-enhancing compounds occur naturally in diesel fuel, but hydro-treating to reduce sulfur levels can alter these compounds.

As diesel fuel is further refined to remove sulfur to comply with federal regulations, it is unintentionally stripped of its lubricating properties. Hydro processing removes sulfur along with significant amounts of aromatic compounds that give conventional diesel fuel adequate lubricating capability. This vital lubrication is a necessary component of the diesel fuel as it prevents wear in the fuel-delivery system. Specifically, it lubricates high-pressure pumps and injectors.

Diesel fuel injection equipment has some reliance on lubricating properties of the diesel fuel. Low lubricity in diesel fuel can cause major engine problems. Measurement of diesel fuel lubricity is important to monitor lubricity additives and final fuel quality. Traditionally, fuel viscosity was used as a rough indicator. The ability of diesel to effectively lubricate engines and components has declined, however, with the introduction of newer low-sulfur diesel fuels and more stringent government regulations.

Diesel fuel pumps and injectors rely on the fuel itself to protect moving parts from wear. Diesel fuels with poor lubricity can lead to pump wear, injector deposits, clogging and eventual vehicle failure. Lubrication properties have become a key parameter of diesel-fuel specifications.

Sulfur Limits

The link between diesel fuel and its ability to protect engines from wear and deposits is well established. This is largely due to the diesel's naturally present sulfur. Sulfur, however, reduces the efficiency of emissions-control devices and creates combustion by-products that increase particulate emissions. Beginning with the Clean Air Act of 1970, the Environmental Protection Agency (EPA) has regulated motor vehicle emissions and pollution, and enacted increasingly strict limits on fuel quality and emissions standards. These mandates have led to additional refining to reduce sulfur levels in diesel.

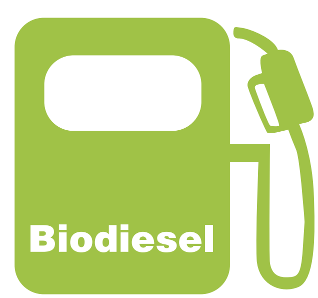
Grade	Max Sulfur
No. 1-D S15	15 ppm
No. 1-D S500	500 ppm
No. 1-D S5000	5000 ppm
No. 2-D S15	15 ppm
No. 2-D S500	500 ppm
No. 2-D S5000	5000 ppm
No. 4-D	

Hydro-treating is a sulfur-removing process used to produce ultra-low-sulfur diesel (ULSD), which has a maximum sulfur level of 15 parts per million (ppm). ULSD was first available for highway use in 2006. Diesel with a sulfur limit of 500 ppm, also known as low-sulfur diesel fuel, became effective in 1993. At that time, the EPA required 80 percent of highway diesel refined in, or imported into, the United States to be ULSD. This changed in 2010, when the EPA required that 100 percent of highway diesel be ULSD. These fuel requirements, coupled with advanced emissions-control technologies, are expected to decrease emissions from these engines by more than 90 percent and help decrease emissions from older diesel engines as well.

A 500 ppm sulfur limit became effective in 2007 for non-road diesel, locomotive and marine (NRLM). By 2012 the sulfur content for NRLM was limited to 15 ppm to enable advanced emissions-control systems. Category 2 and 3 marine engine fuels in the emissions-control area were limited to 10,000 ppm in 2010. By 2015, the limit will drop to 1,000 ppm sulfur.

Biodiesel

Biodiesel has become both a political issue and a viable future source of renewable energy. Biodiesel production, driven by the renewable energy mandate in the U.S., is expected to increase significantly over the next 10 years, reaching 36 billion gallons by 2022. There are many different types and sources of biodiesel with widely varying properties, which adds another variable to the already complicated mix of diesel fuels on the market. Biodiesel presents several performance issues, including lower energy content, poor cold-temperature properties and poor stability.



Biodiesel fuels are made from agricultural products or animal fats, such as soy, corn, coconut, chicken and fish. Agricultural oils have high concentrations of fatty acid methyl esters (FAME), which provide better performance than animal-based oils. Biodiesel has different solvent properties than petro diesel and has been known to degrade rubber gaskets and hoses, predominantly in vehicles built in the early 1990s. Blending a small amount of biodiesel with petro diesel can reduce fuel-system wear, and low levels of biodiesel fuel in high-pressure systems can increase the life of fuel injection equipment that relies on the fuel for lubrication. Biodiesel has virtually no sulfur content, and often is used as an additive to ULSD fuel to aid lubrication.

Biodiesel is commonly blended with diesel for the retail diesel marketplace. It can be used in pure form (100 percent biodiesel is referred to as B100) or may be blended with diesel at any concentration in most injection-pump diesel engines. Common blends include B2 (2 percent biodiesel/98 percent petro diesel), B5 (5 percent biodiesel/95 percent petro diesel) and B20 (20 percent biodiesel/80 percent petro diesel). Tests have shown that the addition of a small amount of biodiesel to petro diesel can significantly increase the fuel's lubricity in the short term.

One main concern is biodiesel's slightly higher viscosity compared to petro diesel. The viscosity of diesel is 2.5 to 3.2 centistokes (cSt) at 40°C, while the viscosity of biodiesel made from soybean oil is between 4.2 and 4.6 cSt. The viscosity of diesel must be high enough to provide sufficient lubrication for the engine parts, but low enough to flow at operating temperatures. If the viscosity is too high it can plug the fuel filter and injection system.

Biodiesel has higher brake-specific fuel consumption compared to diesel, meaning more biodiesel fuel is required to produce the same amount of engine torque. However, B20 biodiesel blend has been found to provide maximum increases in thermal efficiency and lowest brake-specific energy consumption. Biodiesel can also lead to slight decreases in fuel economy and power; on average, it causes about a 10-percent reduction in power. In other words, it takes about 1.1 gallons of biodiesel to equal 1 gallon of standard diesel.

Biodiesel blended into petroleum-refined diesel fuel is increasing the incidence of fuel-filter clogging. Diesel fuels blended with biodiesel are at risk for filter blockage due to the sterol glucosides and bacteria in the fuel. The presence of sterol glucosides at problematic double-digit ppm levels can lead to the formation of a cloudy haze in biodiesel, even at room temperature. The growing number of diverse feed stocks used for biodiesel increases the risk of filter problems.

One of the problems with the fuel itself is the increased NOx in biodiesel emissions. Often, in diesel fuel manufacturing, when the amount of particulate matter in the emissions decreases, a corresponding increase in nitrogen oxides results, which contribute to smog formation.

Biodiesel has an affinity for water and easily absorbs moisture from the atmosphere. The water then supports microbiological growth in fuel storage tanks. At low levels microbes usually don't have a major effect on fuel functionality, but if left unchecked, bacterial growth can block fuel filters.

Improved lubricity is one benefit of biodiesel blends. Levels as low as 2 percent have proven to improve lubricity lost with ULSD in the High-Frequency Reciprocating Rig (HFRR) test. Biodiesel is often not clearly labeled at the pump, creating the potential for confusion, while fuel quality can vary from station to station, creating more concerns for motorists.

Fuel Injection

Clean fuel injectors are critical to engine operation. Keeping nozzles free from deposits helps resist thermal degradation and ensure the proper fuel/air mixture for efficient combustion. Conversely, deposit build-up around these nozzles can interrupt spray patterns, which leads to decreased power, increased smoke, reduced fuel economy and increased levels of exhaust emissions. This is another area where specially formulated fuel additives containing solvents, detergents and dispersants can effectively control deposits.

Traditional fuel injectors feature larger components and are susceptible to carbonaceous deposits forming on the nozzle tips.

Fuel Injection Systems

Fuel injection is a system for admitting fuel into an internal combustion engine. It has become the primary fuel-delivery system used in automotive engines, having replaced carburetors during the 1980s and 1990s. Fuel injectors are designed to control and release the optimal amount of fuel for a given application. Therefore, when a nozzle becomes contaminated or clogged, the fuel spray is impeded and vehicle performance suffers. Good fuel atomization ensures efficient combustion and can be achieved when injectors deliver uniform amounts of fuel.

The HEUI System

A variety of injection systems have existed since the earliest usage of the internal combustion engine. In 1993, Caterpillar introduced Hydraulically Actuated Electronic Unit Injection (HEUI), where the injectors were no longer camshaft-operated. HEUI was developed in the 1990s to increase diesel engine fuel efficiency without loss of engine torque. In addition, these engines had to operate more cleanly to satisfy changing air-emission standards.

In a HEUI injector, oil pressurized between approximately 500 psi to 3,000 psi by a high-pressure oil pump (HPOP) is used to pressurize fuel inside the injector. The HPOP is separate from the engine's oil pump, which provides oil pressure for lubrication; the HPOP is dedicated to providing pressure to the HEUI injectors only.

HEUI injectors are relatively simple in design. The injector can be broken down into two basic sections: a fuel chamber and an oil chamber. A low-pressure fuel pump supplies fuel to the injector and a high-pressure oil pump supplies pressurized oil to the injector. During the injection cycle an actuator allows high-pressure oil to enter the oil chamber of the injector body, applying pressure to an intensifier piston.

The fuel chamber of the injector lies on the other side of the piston. The intensifier piston pressurizes fuel at a rate of seven times the oil pressure. This fuel becomes pressurized before an electric actuator releases it through the injector nozzle.

HEUI injectors had many benefits compared to the mechanical injectors of their time. For example, HEUI injectors allowed for improved throttle response. At low engine speeds, the engine could produce higher fuel pressure for better fuel economy. Injection timing and the fuel rate could also be controlled electronically.

Essentially, the HEUI system reduced exhaust emissions while increasing performance of diesel engines no matter what speed the vehicle was traveling.

Common-Rail Direct Fuel Injection

Common-rail direct fuel injection is a modern variant of a direct fuel injection system for diesel engines. The name ***common rail*** is used because all fuel injectors receive fuel from the same fuel rail, as opposed to individual lines for each injector.

HPCR Systems

High-pressure common-rail (HPCR) systems were designed to supply the demand for more powerful diesel engines while still satisfying various emissions regulations. HPCR systems today are suitable for all types of diesel engines. On diesel engines, HPCR systems feature a high-pressure fuel rail feeding individual solenoid valves, as opposed to a low-pressure fuel pump feeding unit injectors. Third-generation common-rail diesels now feature piezoelectric injectors for increased precision, with fuel pressures up to 2,068 bar, or 30,000 psi.

HPCR injection is a technique for delivering pressurized fuel to injectors. The low-pressure fuel lift pump delivers fuel to a high-pressure injection pump. The injection pump pressurizes fuel up to 30,000 psi and sends it to the common rail. Since pressurized fuel is stored in the common rail, injection pressures are less dependent on engine speed, unlike HEUI and mechanical injection systems. Today's HPCR systems also use piezoelectric injectors, which allow for multiple injection events per cycle.

All of this translates into increased low-end performance, improved fuel economy, reduced engine noise and significantly lower emissions.

Injection System Problems

There are two main causes of fuel injector failure associated with the properties of the fuel itself: ***wear*** and ***deposits***.

Wear

Wear is common and problematic in older fuel injection systems, such as HEUI systems, and potentially more common in HPCR engines since the injectors are smaller, bear higher pressures and activate up to five times more per combustion cycle. Excessive wear can be caused by poor fuel lubricity or abrasion, and lubricity is key to keeping injectors from wearing out.

Ultra-low-sulfur diesel has created a change in fuel quality. ULSD has a maximum allowable sulfur content, which results in the fuel providing reduced lubrication properties. As a result, additives and lubricity improvers are now needed.

Abrasion

Abrasion is the other potential cause of injector failure. Fuel contains small amounts of impurities, and some of these impurities can pass through the fuel filter. Over time a large amount of these impurities can grind the injectors. This abrasion can alter the spray pattern of the injector, resulting in a less efficient injection process and reduced engine performance.

While excessive wear caused by poor fuel lubricity or abrasion is an important factor to consider when evaluating the cause of fuel injector failure, the most common reason for fuel injector failure today is deposit buildup.

Deposit Buildup

The two major types of deposits relating to fuel injector failure are ***external injector deposits*** and ***internal diesel injector deposits***.

External Injector Deposits

External injector deposits, or coking deposits, are usually caused by fuel that does not burn completely and builds up around the fuel injector holes. They can appear dark brown to black in color and carbonaceous or scaly in texture.

External injector deposits, in most cases, won't lead to fuel injector failure. However, these deposits can disrupt fuel spray and lead to inefficient fuel combustion. This inefficient fuel combustion can become noticeable through losses of vehicle power or fuel economy. Diesel additives have been successful in controlling the buildup of external deposits and ensuring efficient performance from the fuel injector.

High-pressure common-rail (HPCR) injectors use smaller, highly engineered components to produce the higher fuel pressures needed for improved combustion. The tighter clearances invite internal diesel injector deposits that interfere with injector needle actuation, reducing performance.

Internal Diesel Injector Deposits

Though they can go unnoticed, common indicators for internal diesel injector deposits include difficult starts, rough idling and sluggish performance.

Unlike external injector deposits, internal diesel injector deposits form on internal parts of the injectors, such as the injector needles and pilot valves. Two categories of internal diesel injector deposits have been found: ***carboxylate salts*** and ***organic amides***. Carboxylate salt deposits are formed from the reaction of sodium ions with carboxylic acids. Organic amides are formed from low-molecular-weight polar materials found as contaminant in some diesel poly isobutylene succinimide (PIBSI)-type detergent additives.

Internal diesel injector deposits appear light grayish and look very similar to coking deposits. They can form in most diesel engines, but are known to cause problems in HPCR diesel engines. This is because HPCR injector systems have smaller, lighter and more intricate moving components that are more susceptible to internal deposit build-up.

HPCR injector systems produce pressures close to 30,000 psi and create an extremely fine fuel mist in the combustion chamber. A fine fuel mist helps the fuel burn more completely, which increases fuel economy and produces fewer emissions. Internal diesel injector deposits can greatly affect the fine fuel mist, which leads to increased emissions and fuel consumption. Internal deposits slow the response, or cause sticking, of moving internal parts, eliminating control of injection-event timing or the amount of fuel delivered to the engine.

To maintain high injection pressure, the injector assemblies have tight clearances. Narrower injector channels and less clearance in the needle guide of HPCR systems result in tighter tolerances in modern injectors, increasing the potential for deposits to cause problems. As a result, minimal material depositing on these injector needles can lead to poor engine performance and even complete sticking of the injector needles. In extreme cases, complete sticking of the injector needles through these deposits can lead to high maintenance costs and vehicle downtime. As internal diesel injector deposits continue to accumulate, they can also cause the same problems of external coking deposits, including loss of power and reduced fuel economy.

OEM Concerns

Several original equipment manufacturers (OEMs) have identified internal diesel injector deposits as a major concern. Many heavy-duty manufacturers have observed internal deposit issues in development, dyno testing or field trials. A growing concern is that the internal diesel injector deposit issue is hindering the development of next-generation engine technologies.

Many OEMs now supply bottled injector-cleaning additives to ensure optimum engine operation. Bottled additives are also available from several reputable non-OEM additive marketers, but making the right additive choice to effectively perform in today's engines shouldn't be a guessing game.

Always check the label and literature to ensure the products used are tested and formulated to eliminate both conventional nozzle deposits and internal diesel injector deposits in both newer and older engines. OEM engine and injector manufacturers report that future injectors may be even more sensitive to internal injector deposits.

Contamination Control

Condensation and water can enter a fuel system and cause a variety of performance-related problems, ranging from a loss of power to the corrosion of internal components. In gasoline-fueled applications, materials are added to the fuel to attract water and move it through the system. In diesel-fueled applications, it is more desirable to separate water from the system instead of suspending it in the fuel. Most diesel applications have a fuel/water separator to help remove the separated water. Engine OEMs prefer this method to remove all possible water from getting to the fuel pump, injectors and engine. When water reaches these components, it can cause corrosion and can turn to steam, potentially causing catastrophic failure. For this reason engine OEMs recommend fuel additives with demulsifiers that help separate water from fuel. Some OEMs do not recommend additives at all simply because additive companies have emulsifiers in their products, which help carry water out of the tank and to the engine to burn.

With the improvements in fuel injector technology for emissions and power purposes, injector components are getting smaller and the clearances between those components are becoming tighter. The cleanliness of the fuel is becoming of greater importance to ensure the clearances between these moving components are not compromised. Small particles of dirt can accumulate in these areas of tight clearance and disrupt normal injector function. When that happens, drivers may experience a loss in power or fuel economy. If the problem is severe enough, ***dirt contamination*** may result in permanent damage to the injectors, requiring replacement. Properly maintaining the fuel system with a good fuel filter is an important key to injector longevity.

As diesel owners in the U.S. and Europe continually increase use of biodiesel, fuel system problems as a result of ***bacterial contamination*** can arise. Biodiesel has an affinity for water and easily absorbs moisture from the atmosphere. This water then supports microbiological growth in fuel tanks. At low levels, microbes usually don't notably affect fuel functionality. If left to spread, however, microbes can cause major problems to the fuel system, including blocked fuel filters, plugged fuel lines, injector deposits and fuel system corrosion. Maintaining a clean fuel supply is important to the longevity of the fuel tank and fuel delivery components.

Diesel Grades/Seasonality

Standard diesel fuel comes in two grades: ***diesel #1*** and ***diesel #2***. Diesel #1 fuel has lower viscosity and a lower pour point than diesel #2, making it preferable in cold weather. However, diesel #1 fuel produces approximately 95 percent the energy output of diesel #2, resulting in reduced fuel economy and lower horsepower.

Diesel #2 is used in warmer weather and can be mixed with diesel #1 to produce a more effective cold-weather fuel. Consumers, however, don't have to worry about mixing diesel fuels or which type of diesel fuel to use because all diesel automakers allow you to use #1 or #2 diesel.

Diesel fuel is measured by its viscosity and, like any oil, diesel fuel becomes thicker at lower temperatures. Under extreme conditions, it can gel and cease to flow. Diesel #1 fuel flows more easily than diesel #2, which makes it more efficient at lower temperatures. The two types of fuel can be blended, and most service stations offer diesel fuel blended for local weather conditions. If you plan to drive in cold weather, choose diesel fuel rated at least 10° lower than the coldest temperatures you expect to encounter.

Cold Weather

Cold-temperature properties are one of the most publicized diesel fuel issues, especially as more biodiesel is blended with petro diesel. ***Cloud point***, ***cold filter plugging point*** (CFPP) and ***pour point*** are all indicators of cold-weather diesel-fuel performance.

- **Cloud point** - The point at which wax crystals begin to form in diesel fuel as the temperature drops

- **Cold filter plugging point** - The point at which wax crystals allowed to form in untreated diesel fuel clog the fuel filter

- **Pour point** - The lowest temperature at which fuel maintains its ability to flow

There are currently no national standards in Canada, Mexico or the U.S., and there are significant issues created by poorly blended fuels. In fact, there are significant and worsening problems associated with cold-weather performance due to the variability in fuel sources across countries and regions.

All diesel fuels contain paraffins (wax). The hydro-treating process used to desulfurize fuel increases its wax content. Normally the wax is a liquid in fuel and is important to diesel components because of its high cetane value. High wax concentrations in fuel can lead to cold-weather problems for many diesel-powered engines. As the temperature drops, wax crystals form in low-sulfur diesel. The fuel becomes thicker and gradually gels until it finally clogs the filter, fuel lines or injectors. If the temperature is sufficiently low, excessive crystal formation can block the fuel filters and lines, causing difficult engine starts and the potential for the engine to stop running due to fuel starvation. This effect can be minimized and controlled with the use of pour-point depressants; as long as waxes remain liquid, they pose no threat.

Some consumers blend #2 diesel with #1 diesel to create a fuel that can operate in lower temperatures. It is not nearly as efficient and costs more.

Blending fuel is one way to lower the CFPP. CFPP is based on a standardized test that indicates the lowest temperature at which the diesel fuel still passes through a standardized filtration device in a specified time when cooled under a certain condition. In layman's terms, this means that as the ambient temperature decreases, the fuel is still able to continuously flow to the engine and keep it running until the CFPP is reached. Understanding this value helps determine the lowest possible temperature at which the engine will operate.

Similarly, the Low Temperature Flow Test describes the winter performance of diesel fuel with improver additives. Both the CFPP and low temperature flow test temperature is higher than the pour-point temperature at which diesel fuel loses its fluid characteristics, rendering pumps inoperable. This condition happens when a fuel reaches a low enough temperature whereby enough wax crystals have formed to prevent any movement in the oil. For #2 diesel, this is usually around 20°F; however, some fuels begin wax formation at temperatures as high as 40°F. For the fuel to flow again, its temperature must be increased. Cold-flow-improver additives are commonly added to diesel or biodiesel to reduce the formation of wax crystals in colder temperatures.

Winter Problems

The standard diesel at every pump is required to meet certain CFPP characteristics. The Standard Specification for Diesel Fuel Oils (ASTM D975) contains no requirements for treating the diesel fuel, but instead calculates minimums and averages to meet the majority of ambient temperatures.

ASTM D975 contains overview maps that show the expected tenth-percentile temperature for every month for each state. Per these guidelines, gas stations offer winter diesel ready for the road based on averages and not actual temperatures. There are two ways to achieve this—through ***winter-blend diesel*** and ***winterized diesel***.

Winter-blend diesel is produced by blending #2 diesel with some percentage of #1 diesel (sometimes referred to as kerosene). Blending occurs at the fuel refinery prior to delivery to fuel stations. Winterized diesel is produced when #2 diesel has been treated with additives, also done at the refinery. This additive treatment is a less expensive way to enhance the quality and reliability of #2 diesel fuel. Most stations offer a suitable diesel fuel during cold-weather conditions. In regions that have consistently cold winter weather, some stations offer #1 diesel at the same pump, allowing drivers to choose between #1 diesel and winter blend or winterized diesel. The option to purchase a winter blend or winterized diesel varies depending on the location of the service station and the fuel supplier. Stations most often post at the pump which fuel they sell.

Cold-flow additives, added to make winterized diesel, are designed to prevent gelling and enhance diesel fuel cold-weather performance. They work by modifying the size and shape of the wax crystals, which allows the treated diesel to operate at lower temperatures without problems.

Modifying the wax crystal formation in fuel lowers the CFPP, eliminating fuel-line freeze, preventing fuel-filter icing and reducing corrosion due to moisture caused by condensation in the fuel tank. The use of cold-flow additives reduces or even eliminates the need to blend diesel fuel with #1 diesel.

Overall, continuous use of cold-flow additives during temperatures below 40°F results in easier vehicle starting, better fuel economy, less engine wear, reduced downtime and lower fuel costs.

Preventive Maintenance

Problems associated with diesel injectors can range from poor engine performance to expensive repairs, and injector replacements can cost from $5,000 to $10,000, depending on the vehicle model and number of injectors. With today's high-pressure common-rail fuel systems, deposit formation is inevitable; diesel owners can either clean injectors with regular use of a high-quality diesel fuel additive, such as AMSOIL Diesel Injector Clean, or neglect them until they need replacing.

A comparison illustrates the benefits of preventive maintenance compared to replacement. For a Chevrolet truck with a 6.6L Duramax diesel engine, replacing the injectors can cost about $7,000, not counting a tow truck bill and the inconvenience of getting stranded and suffering from downtime.

INJECTOR REPLACEMENT	CONTINUOUS use of AMSOIL Diesel Injector Clean
$5K-$10K	$768

Regular use of AMSOIL Diesel Injector Clean with every tank of fuel offers a far less expensive alternative. If someone keeps his or her diesel pickup for 140,000 miles, using Diesel Injector Clean costs approximately $768. The numbers speak for themselves. Regular fuel-system maintenance is the most cost-effective method of keeping diesel engines clean and performing well.

To determine the lifetime cost of continuous use of AMSOIL Diesel Injector Clean, follow these steps:
1) Annual vehicle mileage / mpg = gallons of fuel consumed per year
2) Gallons per year / 5 oz. (recommended maintenance dose of Injector Clean) = oz. Injector Clean needed per year
3) Oz. Injector Clean per year / 16 oz. per bottle = bottles per year
4) Bottles per year x $7.90 per bottle = annual cost
5) Annual cost x years of vehicle ownership = lifetime cost of using Diesel Injector Clean

Diesel Fuel Additives

The primary purpose of fuel additives is to maintain the function and condition of the fuel-delivery system. Fuel additives may be formulated for intermittent use, such as to clean injectors, address changes in ambient operating temperatures or combat fuel-quality issues. Additives are most effective, however, when used on a continuous basis, especially to prevent wear and deposits. The following types of additives, which many additive companies combine for ease of use, are designed for specific purposes.

Cetane-number improvers increase the overall efficiency of diesel fuel combustion. This results in reduced engine noise and smoke, lower emissions and better cold-weather starting.

Injector-cleaning additives are formulated to prevent internal diesel injector deposits and external deposits from forming in the nozzle area. Fuel injectors are integral components of the fuel-delivery system, and they require continuous maintenance to ensure proper operation.

Lubricity additives are used to combat the low lubricity associated with ultra-low-sulfur diesel. Fuel pumps and injectors need lubricity additives to reduce wear from metal-to-metal contact.

De-icing additives use alcohols or glycols to prevent ice formation that can result in blocked fuel lines and a blocked fuel filter. The alcohols and glycols act by dissolving in water, lowering the diesel fuel's freezing point.

Additives that lower a diesel fuel's pour point are called ***low-temperature-operability additives***. Also known as cold-flow improvers, most of these additives are polymers that combat the wax crystals and help lessen their effect on the fuel flow by modifying their shape.

Antioxidants can be added to unstable fuels to fight the chain reactions associated with oxidation. Acid-base reactions create fuel instability, and the stabilizers needed to prevent these reactions typically are strong basic amines. When small amounts of certain metals are dissolved in diesel fuel, such as copper or iron, a metal deactivator is needed.

Contaminant-control additives handle the chemical pollutant problems associated with diesel fuel supply and storage. Fuel can become contaminated with bacteria and fungi due to air or water exposure. These types of additives are designed to control or eliminate contaminants from becoming larger issues.

A small amount of contaminants may not be a problem, but excessive contamination can corrode the fuel system and plug filters. This happens most in stored fuel, and the best additive to use is a biocide that readily mixes with both fuel and water. Demulsifiers and corrosion inhibitors also help contain contamination.

Conclusion

Diesel fuel quality is highly variable, and consumers and their vehicles can suffer. Wear within the fuel-delivery system must be minimized to maintain peak operating condition. Wear control is important to maintaining fuel-flow control, precise metering of the fuel and long-term component life for maximum vehicle performance and fuel economy. If high-quality diesel fuel designed specifically for the local climate was the only fuel available to everyone, there would be little reason for diesel fuel additives. Since this is not the case, there are a number of diesel fuel additives on the market formulated to solve specific issues found with diesel fuel.

Fuel additives are most effective when used on a continuous basis. It takes time for a system to accumulate deposits, and it takes time for contaminants to be removed. Using fuel additives as part of a regular preventive maintenance program is a proactive approach to preventing problems from surfacing in the future.

The multitude of diesel fuel additives on the market, each promising a range of benefits, can be confusing to customers. Additives can be separated into two main categories: multi-purpose additives that try to address several issues in a single formulation, and specialized products formulated to target specific performance areas. Although they may seem convenient, all-in-one additives can fail to deliver the effectiveness customers want. As performance concentrates, AMSOIL diesel fuel additives make no sacrifices; they are purpose-built to address specific performance needs and deliver maximum results.

AMSOIL offers a variety of top-performing diesel additives for all on- and off-road diesel-powered applications. Each is formulated using the best available chemistry at maximum concentration for quick results, promoting peak performance and reduced maintenance. By learning about these products and understanding the issues facing diesel owners, AMSOIL Dealers can help solve problems while keeping customers' equipment running as designed for as long as possible.

AMSOIL Cetane Boost improves combustion efficiency to increase power in diesel engines. It raises cetane three to seven numbers while also improving low-temperature starting, fuel ignition quality and reliability.

AMSOIL Diesel Injector Clean is a total system cleaner and lubricity improver for all types of heavy- and light-duty diesel engines, including high-pressure common-rail (HPCR) designs. Its outstanding formula cleans all deposits, including carbon deposits on the nozzle and internal diesel injector deposits on the pintle. Formulated with ultra-low-sulfur diesel fuel (ULSD) in mind, it effectively cleans fuel injectors and combustion chambers for improved efficiency and better sealing. It minimizes soot-loading, improves the oxidation and thermal stability of diesel fuel, improves fuel economy by up to 4.5 percent, restores horsepower and protects against water contamination. Diesel Injector Clean is compatible with all types of exhaust emission systems, including diesel particulate filters (DPF). It is also recommended in heating oil furnace applications.

AMSOIL Diesel Cold Flow is recommended for low-temperature applications below 40°F. It effectively modifies wax crystal formation at low temperatures to depress diesel fuel pour point and improve cold-flow filtration properties. It lowers the cold filter plugging point (CFPP) by as much as 34°F and decreases the need for #1 diesel fuel. Diesel Cold Flow contains jet-fuel-type deicer to help prevent ice formation in fuels contaminated with water. It is compatible with diesel particulate filters (DPF).

AMSOIL Diesel Injector Clean + Cold Flow is a premium, year-round diesel fuel additive that combines the superior detergency and lubricity of AMSOIL Diesel Injector Clean with the excellent anti-gelling properties of AMSOIL Diesel Cold Flow in one convenient package without sacrificing performance.