May 2019

Automotive Technology Update

Diesel Fuel Additives

Need to Know

- Diesel fuel contaminated with water and particulates can cause serious problems such as microbial growth, fuel filter plugging and damage to fuel system components.
- Diesel fuel can gel at low ambient temperatures, and water in the fuel can freeze, resulting in no-start or drivability problems.
- Carbon deposits on fuel injectors and in diesel engine combustion chambers can cause rough idling, black exhaust smoke and/or decreased performance.
- Diesel fuel with a low cetane number can cause increased engine noise and decreased engine performance and fuel economy.
- Diesel fuel additives are available from vehicle manufacturers, engine suppliers and aftermarket sources to combat water contamination, fuel gelling, carbon deposits and low cetane ratings.
- Automakers recommend the use of OEM-approved fuel additives, and then only on a short-term basis to address specific climate, fuel and/or engine performance issues.
- Automakers do not recommend the continuous use of fuel additives because they could damage fuel system components, particularly when used in too-high concentrations.
- The most common source of contaminated diesel fuel is poorly maintained retailer storage tanks.
- Motorists experiencing diesel engine performance issues should consider trying a different fuel retailer before using an additive.

Introduction

Diesel engines are a workhorse of the U.S. economy, from powering trucks and trains that transport freight across the country, to the diesel-powered equipment used in the agricultural and construction sectors. The high torque output, superior fuel efficiency and longer life of the diesel engine makes it an ideal powerplant for such heavy-duty uses.

A Ford 6.7-liter Power Stroke diesel engine. (Image: Ford)

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What is an ATU?

AAA Automotive Technology Updates (ATUs) provide expert information on a variety of topics related to modern vehicles. Some feature in-depth answers to common questions about automobile use and maintenance. Others explore new technologies in today's rapidly evolving automobiles. For additional information, visit www.AAA.com/autorepair.

On the other hand, diesel engines are relatively rare in U.S. passenger cars, making up only 3 percent[1] of new vehicle sales. The most common installations are in light-duty trucks used to tow trailers or haul large loads, although diesel engines are also found in some coupes and sedans where they offer very good fuel economy.

Gasoline and diesel engines share a basic mechanical structure, but that is where the similarity ends. Their fundamental operating characteristics are quite different, and each requires a fuel that is specifically formulated for the engine design. Diesel fuel is less highly refined than gasoline, which means it has properties that require special maintenance procedures and can result in unique operational issues. Diesel fuel from the pump contains additives that help combat most problems, but sometimes the use of additional aftermarket additives can help prevent or resolve certain issues.

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Diesel Engines

The basic operation of a diesel engine is relatively simple. Diesel fuel is injected into the cylinder just before the piston reaches top dead center on the compression stroke. When the air in the cylinder becomes hot enough from being compressed it ignites the fuel mixture, forcing the piston down for the power stroke.

In addition to their lack of spark plugs, diesel engines differ from their gasoline counterparts by having much higher compression ratios and not throttling the intake air. Instead, engine speed and power are regulated by the amount of diesel fuel injected, and the timing of those injections.

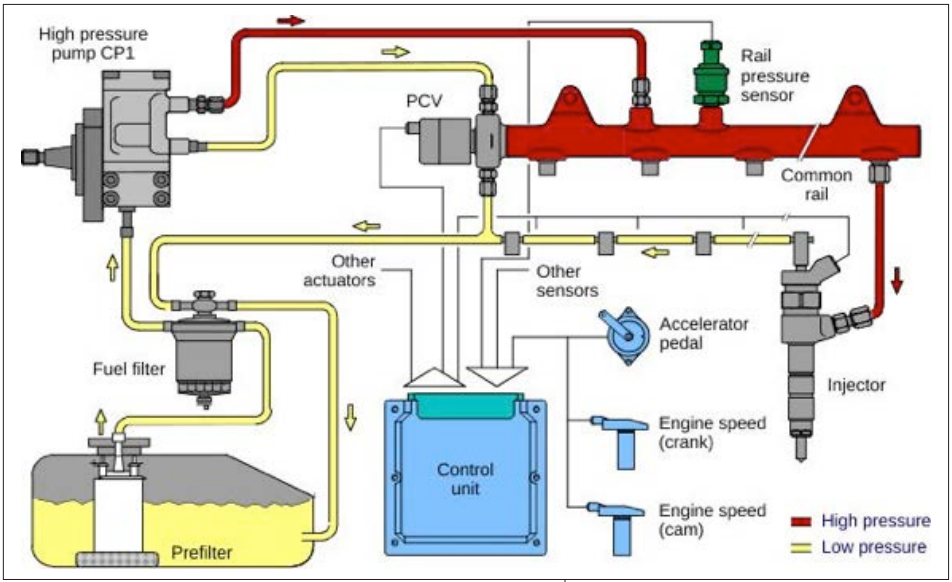
Fuel Delivery

Older diesels used mechanical fuel injection systems that pumped fuel to each injector separately, but modern engines use extreme high-pressure fuel pumps that supply a common fuel rail that connects to all of the injectors. Another difference is that older diesel fuel injectors were simple spring-loaded valves, while modern diesels use computer-controlled piezoelectric injectors capable of providing up to ten separate fuel injections per power stroke. Multiple injections, together with selective catalyst reduction (SCR) systems, help diesel engines meet stringent exhaust emission targets. In addition, a small pilot injection of fuel made before the main injection events helps to reduce combustion noise.

The high-pressure fuel pump, common rails and injectors of a modern diesel engine. (Image: Bosch)

The complexity of modern diesel engine fuel systems makes them far less tolerant of fuel quality issues than diesels of the past. Practices that could once be gotten away with, such as filtering used cooking or motor oil and adding it to the fuel tank, can cause serious and expensive damage to modern diesel fuel systems. The only fuels suitable for use in today's diesels are products refined, blended and retailed expressly for that purpose.

Diesel fuel not only produces power, it is continuously circulated through the fuel system to cool and lubricate the fuel pump, common rail and fuel injectors. Piezoelectric injectors operate at pressures as high as 39,000 psi.[2] To properly control fuel delivery at such pressures, the injectors require extremely precise running clearances of around 0.002 mm (2 microns).[3] With such small clearances, the lubricity and cleanliness of diesel fuel is the only thing that keeps injectors from scoring or seizing. As a result, fuel quality, filtration and the formulation of any additives can have major effects on diesel engine fuel system performance and durability.



Schematic drawing of a high pressure common rail diesel fuel injection system. (Image: Dieselnet)

Diesel Fuel

As stated earlier, diesel fuel is a less refined petroleum product compared to gasoline and it tends to contain more elements of the crude oil from which it was made. One of those elements is sulfur, and in the early 1990s diesel fuel in the U.S. often had sulfur levels as high as 5,000 ppm. While sulfur has some beneficial lubricating properties, it is disastrous for the environment when emitted in diesel exhaust as particulate matter and sulfur-dioxide.[4] To help combat these pollutants, low-sulfur diesel (LSD) fuel with a maximum sulfur content of 500 ppm was introduced in the U.S. in 1993.

LSD was a good first step to reducing exhaust emissions, but 500 ppm of sulfur was still too high to allow the use of SCR systems, which are necessary for diesel engines to meet more recent emissions standards. As a result, in 2006 ultra-low sulfur diesel (ULSD) containing less than 15 ppm of sulfur became required for all on-road diesel vehicles.[5] Even at this low level, the U.S. is only ranked 59th in the world in terms of diesel fuel quality due to sulfur concentrations.[6] The Europeans and Japanese are in the lead, requiring less than 10ppm of sulfur in diesel fuel sold in their markets.

Petroleum remains the primary source of diesel fuel, but in recent years several alternative fuels have become more common. Intended to reduce reliance on imported oil and/or make use of renewable energy resources, these fuels are discussed in the following sections.

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Biodiesel

The use of biodiesel fuel is growing in popularity as automakers design their diesel engines and fuel systems to accommodate varying levels of this renewable fuel. Biodiesel is derived from vegetable oils, recycled cooking greases/oils and animal fats, which makes it a green choice for fuel buyers who are conscious of their energy usage.[7]

Approximately 75 percent of new light-duty, diesel-powered vehicles in the U.S. can tolerate regular diesel fuel blended with up to 20 percent biodiesel (B20). The other 25 percent (mostly European vehicles) are typically approved to run on a maximum of 5 percent biodiesel (B5).[8] Drivers of diesel vehicles should check their owners' manuals before using fuel containing biodiesel to make sure they do not exceed the approved safe level for their engine.

Biodiesel may benefit the environment, but it can also cause problems when used in concentrations higher than those recommended by automakers. Contaminants in biodiesel, such as sterol glucosides and saturated monoglycerides, can buildup on fuel filter media and increase the likelihood of filter plugging – even in moderate temperatures. In higher concentrations, including B20, biodiesel has a solvent effect on the walls of fuel retailer storage tanks,[9] which can release sediment and other contaminants that may then be pumped into vehicle fuel tanks.

A pump that dispenses both E85 gasoline and B5 biodiesel "green" fuels. (Image: RCB, CC BY 2.0)

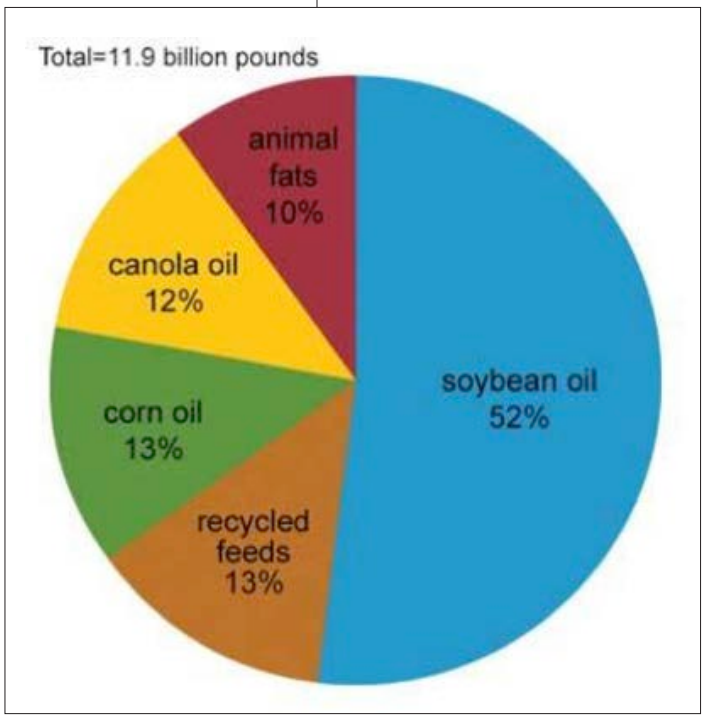
Due to its organic base stock, biodiesel is more likely than regular ULSD fuel to promote microbial growth in fuel tanks, especially when stored for longer periods or in the presence of water. Biodiesel can also reduce the efficiency of diesel fuel system water separators because its strong molecular bond with water can pass moisture through to the fuel pump and injectors, potentially resulting in corrosion and other damage.

Vehicles operated on biodiesel sometimes require more frequent fuel filter replacement and draining of the water separator. Motorists should check their owners' manuals for the maximum allowable concentration of biodiesel, and also any changes to the recommended maintenance schedule when biodiesel is used.

Biomass-Based Diesel

Biomass-based diesel[10] fuel differs from regular biodiesel because it is derived from soybean, corn and canola oils in addition to recycled feedstocks and animal fats.[11] Biomass-based diesel is considered renewable because it is at least partially made of oils from plants that can be grown on an annual basis. Similar to biodiesel, the EPA promotes biomass-based diesel because it supports U.S. farmers and reduces dependency on foreign oil.

Because it is made from organic materials and waste fats, biomass-based diesel shares some of the same downsides as biodiesel. Similar fuel system problems may be observed, and can be mitigated through regular fuel filter and water separator service.



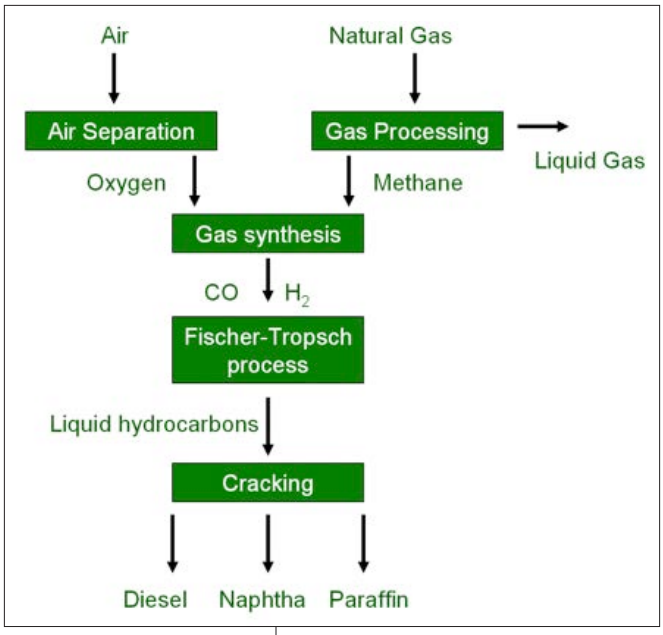
2017 Feed stock inputs for biomass-derived diesel fuel. (Image: U.S. Energy Information Administration)

GTL Diesel

Another form of diesel fuel is called gas-to-liquid (GTL)[12] diesel. This is a synthetic product produced from natural gas using the Fischer-Tropsch[13] chemical process developed in the 1920's. Natural gas is fairly abundant, and using it to produce GTL diesel supports oil company efforts to use products other than crude oil for the production of liquid fuels.

GTL diesel is very "pure" and has performance attributes similar to ultra-low sulfur diesel without the aromatic, sulfur and metal components common in traditional diesel fuel. GTL diesel also has a higher cetane level and flash-point than conventional fuel so engines running on it typically deliver greater power and smoother operation with fewer exhaust emissions.[14]

Because GTL diesel lacks the waste greases/fats/oils and organic byproducts that are found in biodiesel and biomass-based diesel, it does not share their tendencies to increase microbial growth, decrease water separator efficiency and accelerate fuel filter plugging. GTL diesel is a very good alternative to conventional ULSD. However, the high cost of refinery development for the gas-to-liquid distillation process is the primary reason this technology has not become more widespread.



The process used to create gas-to-liquid diesel fuel. (Image: Dexcel at English Wikipedia, CC BY-SA 3.0)

Fuel Storage Issues

Motorists usually believe that diesel fuel delivered to gas stations is clean and free of contaminants, but this is not always the case. A recent study[15] found that in a single delivered tanker load (7,500 gallons) of ULSD there was 1 cup of dirt, 1 to 2 gallons of water, 375 gallons of biofuel (B5), 1 gallon of glycerin and 5-40 gallons of fuel additives. While most of these substances are supposed to be in the fuel blend, dirt and water definitely are not.

Additional contaminants can enter diesel fuel while it is stored at fuel retailers before being dispensed. Regular fuel storage tank maintenance is vital to minimizing contaminants. Storage tanks should be cleaned regularly, and the fuel in them "polished" to remove sediment, water and microbial sludge. It is best if this treatment if followed up with the addition of a biocide to kill off any remaining microbial growth and help prevent its recurrence.

Gas stations have filters on the outlets of their pumps to capture particulates, but in many cases those filters only capture particles that are 30 microns and larger in size. U.S. market fuel survey data from 2013-2014 indicated that most sediment in diesel fuel is smaller particles in the 4 to 10-micron range, which means the pumps at diesel fuel retailers often pass contaminants straight through into vehicle fuel tanks. Vehicle fuel system filters and water separators capture most of these contaminants, but doing so comes at the cost of more frequent servicing for these components.

A service truck equipped for fuel storage tank cleaning and fuel polishing. (Image: Oscar W. Larson Co.)

The TOP TIER program,[16] which for many years has promoted a voluntary standard for higher-quality gasoline, established a standard for diesel fuel in 2017 that requires suppliers to meet more stringent performance, lubricity and cleanliness requirements. Retailers that participate in this program sell diesel fuel that exceeds minimum government requirements. For additional information visit the TOP TIER website at **https://www.toptiergas.com**.

Fuel Problems/Additives

Diesel engines offer many positive performance attributes, but the nature of diesel fuel means they require more frequent preventative maintenance to ensure trouble-free operation. In addition, diesels can suffer unique operational issues, especially in cold weather. Even when using high-quality fuel, owners of diesel-powered vehicles may find aftermarket fuel additives helpful in addressing a number of issues discussed below.

Water-Related Problems

Water is common in diesel fuel systems. Where does it come from? To begin with, diesel fuel is mildly hygroscopic;[17] it attracts and absorbs moisture from out of the air. Also, water often enters the fuel system from poorly maintained storage tanks at diesel fuel retailers. If water is not removed from the fuel system regularly it can lead to microbial growth, corrosion damage to fuel injection components and fuel blockages due to icing in winter months.

Water contamination of diesel fuel is such a major concern that most diesel-powered vehicles are equipped with a water separator in the fuel filter assembly or elsewhere in the fuel system. Some, but not all, separators have water detection sensors that let the vehicle operator know when it is time to drain the separator. The water separator must be drained at regular intervals as part of routine diesel engine maintenance, and more often if higher levels of water contamination occur.

Microbial Growth

Diesel fuel can maintain a certain amount of water in suspension. However, if the water concentration becomes too great, it falls out and settles to the bottom of the fuel tank because water is denser than diesel fuel. This layering of diesel fuel and water is called phase separation and it promotes microbial growth, especially when using biodiesel.[18]

A diesel fuel filter plugged as a result of microbial growth.
(Image: Nulon Australia)

Depending on the type of organisms involved, microbial growth can occur on the fuel tank walls or at the water/fuel interface where oxygen in the water allows bacteria and fungi in the fuel to multiply, forming a thick gooey substance that can block fuel lines and plug the fuel filter. Aftermarket biocide fuel additives[19] are available to help prevent and neutralize microorganism growth. However, if a problem goes untreated for too long, fuel filter replacement and a fuel system flush may be necessary to restore proper engine operation.

As with the fuel retailer supply tanks discussed earlier, vehicle fuel tank cleaning and fuel "polishing"[20] is an effective method to address microbial growth, especially when it is impractical to remove a tank for flushing. In this process, an external fuel pump, multi-stage filter and water separation system is used to flush a dirty tank until it is free of contaminants. The equipment necessary to perform this operation is available at some diesel repair facilities, and there are companies that offer mobile service as well.

Corrosion

Another major concern with water in diesel fuel is corrosion of fuel system components such as the high-pressure supply pump, the fuel injectors and various other parts and fittings. Water will attack any unprotected surfaces causing corrosion and ultimately part failure. Corrosion inhibitors are part of most diesel fuel additive packages to lessen the harmful effects of any water that may be present.

Icing

The final concern with water that settles to the bottom of the fuel tank, fuel filter and water separator is that it can freeze at low ambient temperatures and block the fuel supply system. Aftermarket diesel fuel de-icing additives are available to help combat this problem. These products contain alcohol and emulsifiers that absorb and break up water molecules so they can be passed through the fuel system and burned in the combustion chamber. De-icing additives must be added to the fuel and circulated throughout the fuel system *before* temperatures drop to the point where icing might be a problem. An additive will not thaw a frozen diesel fuel system after the fact. The only cure at that point is to wait for warmer temperatures or have the vehicle towed to a heated shop where the fuel can return to a liquid state, water can be drained from the separator and an anti-icing additive can be installed.

Fuel Gelling

The relatively low volatility of diesel fuel means diesel engines can be susceptible to starting problems in cold weather. For example, when a diesel engine is cold and ambient temperatures are low, the amount of heat generated by compressing the intake air may not be sufficient to ignite the air-fuel mixture. To address this problem, diesel engines use glow plugs that pre-heat the air in the cylinders to aid cold-engine starting. Electric block heaters that keep the engine coolant warm are also often used to improve cold-weather starting performance.

However, having enough heat to ignite the fuel is of no use if fuel is not being injected. Fuel flow can be blocked in low ambient temperatures where diesel fuel has a tendency to gel. This occurs because diesel fuel contains straight and branched chain hydrocarbons (paraffin waxes) that congeal in cold weather.[21] Wax formation can be intensified with biodiesel fuel blends, and the results can range from a plugged fuel filter to fuel that has gelled to the point that it will no longer flow through the fuel lines.

A fuel filter covered with paraffin wax from gelled diesel fuel. (Image: Advanced Fuel Solutions, Inc.)

Before deciding that a cold weather diesel engine no-start problem is the result of fuel gelling, keep in mind that most diesel fuel systems have a water separator that must be drained at regular intervals. As mentioned earlier, if this important maintenance operation is overlooked, water in the separator can freeze and plug the fuel system at temperatures above those where diesel begins to gel.

Aftermarket additives are available that help prevent wax formation and lower the pour point of diesel fuel, improving fuel flow in cold weather. However, such additives must be added to the fuel tank and circulated throughout the fuel system *before* temperatures drop to the point where gelling might be a problem. An additive will not "thaw" a gelled diesel fuel system after the fact. The only cure at that point is to wait for warmer temperatures or have the vehicle towed to a heated shop where the fuel can return to a liquid state and an anti-gelling additive can be installed. In severe cases, a wax-plugged fuel filter will need to be replaced to restore fuel flow.

Some diesel-powered vehicles are equipped with fuel heaters, often built into the fuel filter assembly, that help prevent gelling. And, at least one automaker suggests blending #1 diesel fuel (cold weather) with #2 diesel fuel during winter months. Thankfully, cold starting issues are less of an issue with modern diesels due to their improved glow plug and fuel delivery systems. However, neither of these will help if there is frozen water or gelled fuel in the system.

Cetane Improvers

As described earlier, diesel engines use super-heated compressed air to ignite diesel fuel that is injected into the combustion chamber. However, once the fuel is injected there is a short time, called ignition delay, before it begins to burn.[22] The amount of ignition delay in a diesel engine is determined, in part, by the cetane rating of the fuel. Fuels with a higher cetane number ignite faster and burn more completely for smoother running, increased engine performance and greater fuel efficiency.

Diesel fuel's cetane rating is essentially the inverse of the octane rating for gasoline. Increasing the cetane rating of diesel fuel enables the fuel to ignite faster, while increasing the octane of gasoline helps prevent ignition of the fuel before the spark plug fires. One thing cetane and octane have in common is that using a fuel with a higher rating than that recommended by the vehicle manufacturer provides no additional benefits.

Additives for diesel fuel that contain cetane improvers help the engine run smoother, and motorists sometimes report a small increase in engine performance and fuel efficiency. As an alternative, premium diesel fuel is available at some retailers. Premium diesel has a higher cetane number than regular ULSD and has been shown to increase engine power by as much as 4.5 percent.[23] Of course, motorists should weigh the performance and fuel economy benefits of premium diesel fuel against its higher cost.

Fuel Lubricity

Lubricity is a critical property of diesel fuel due to the extreme pressures and very tight tolerances in modern common rail fuel injection systems. In the past, diesel fuel contained sulfur that served as a natural lubricant, but that changed with the introduction of ultra-low sulfur diesel (ULSD) fuel in 2006. When ULSD is refined, the hydro desulfurization (HDS)[24] process removes much of diesel's inherent lubricity, so lubricant packages are now added when diesel fuel is blended at distribution terminals to ensure that the fuels meet SAE performance guidelines. Aftermarket fuel additives are also available that enhance lubricity and provide additional fuel system protection.

A cutaway view of a piezoelectric diesel fuel injector whose tight tolerances rely on fuel lubricity to prevent damage. (Image: L. Kenzel, GNU FDL 1.2 or later)

Fuel Stability

Over time, diesel fuel can become unstable and form insoluble organic particulates and soluble gums that can clog fuel filters and contribute to fuel injector deposits. To minimize this effect, fuel stabilizers are added when diesel fuel is blended at the distribution terminal. However, fuels that are stored over longer periods can deplete this additive. Aftermarket additives with extra fuel stabilizers can help mitigate particulate and gum formation by maintaining fuel stability.

Engine and Fuel System Clean-Up

Engine oil and unburnt diesel fuel can cause carbon deposits in combustion chambers and on the tips of the fuel injectors. These deposits can negatively affect the atomization and distribution of fuel in the combustion chamber. Modern diesel fuel injectors have very small holes on their tips that distribute atomized fuel in a radial pattern. Unfortunately, these holes can be partially or completely blocked by deposit buildup over time. When this occurs, the engine may run rough or hesitate under acceleration. Aftermarket fuel additives with special detergents are available to help remove carbon deposits and restore proper engine operation.

Diesel fuel additives designed to counteract carbon buildup come in two forms – periodic clean-up and restorative clean-up. Additives such as GM's Diesel Fuel Conditioner are for occasional use and contain detergents that help remove carbon deposits that have built up over time. However, this type of product may not provide relief in engines that have severe deposit buildup that is reducing power or fuel economy.

A typical spray pattern for a clean diesel fuel injector. (Image: GTS Engine - Diesel Fuel Injection)

Additives such as GM's Fuel System Treatment Plus-Diesel, designed for use only when necessary, contain highly-concentrated detergents that can breakup carbon deposits and restore power in a short time. High-detergent restorative additives reduce fuel lubricity and should not be used regularly or in too-high a concentration or fuel system damage may result.

Additive Availability

Diesel fuel additives are available at car dealers, fuel retailers, auto part stores and vehicle repair centers. Since fuel additives can be added to the fuel tank without any special tools, many motorists perform this preventative maintenance procedure on their own. While the process is simple, care must be taken when using additives to prevent damage to the vehicle fuel system. Fuel additives are designed to work with specific quantities of fuel. For example, 16 ounces of an additive may treat 30 gallons of fuel. Failure to carefully measure and mix additives with diesel fuel can result in over-treating a fuel system, which can damage expensive fuel injectors and injection pumps.

Additive manufacturers often bundle multiple types of additives into a single product for consumers. For example, a fuel conditioner might include a cetane number improver, lubricity enhancer, fuel stability supplement and added corrosion prevention in one bottle. Motorists should consult vehicle owners' manuals to determine acceptable fuel additive packages for their vehicles and operating conditions.

Automaker Recommendations

Automakers invest heavily in research and development to ensure that their vehicle powertrains meet stringent fuel economy, emissions and reliability targets. A significant part of engine reliability testing is evaluating engines and fuel systems using a variety of laboratory and on-road tests to ensure the vehicle can operate in diverse global markets where fuel and additive qualities can vary dramatically.

Automakers cannot possibly test every available aftermarket additive, so they generally recommend only their own branded additives, which have been tested for use in their engines and fuel systems. Vehicle manufacturers do not recommend aftermarket additives because they cannot validate the compatibility of untested products. Cummins (Ram and Nissan truck diesel engine supplier) is a rare exception to this rule; they approve the use of Power Service additives[25] in their diesel engines.

Power Service diesel fuel additives approved by Cummins. (Image: Power Service)

Just because an aftermarket diesel fuel additive is not automaker approved does not mean that it is ineffective or unsafe. However, fuel system damage that could be blamed on non-approved additives might cause an automaker to deny warranty coverage for a fuel system or engine problem. In such cases, the additive manufacturer would need to take responsibility. Keep in mind that high-pressure common rail diesel fuel systems are very complex and expensive to repair; having to replace the fuel pump and injectors can cost $5,000 to $9,000.

In general, automakers also do not recommend the use of any diesel fuel additives (even their own) on a continuous basis. Approval is usually granted on a conditional basis to address specific problems such as cold weather fuel gelling and icing, cetane number improvement, carbon deposit removal and other issues discussed earlier.

A list of diesel fuel additives that are registered for use in the U.S. can be found on the Environmental Protection Agency (EPA) website[26] at **www3.epa.gov/otaq/fuels1/ffars/web-dies.htm**. However, it is important to recognize that EPA registration only means that an additive will not damage vehicle emission control systems. EPA registration is not an indication of product quality or effectiveness.

An automaker approved diesel fuel conditioner. (Image: General Motors)

To Learn More

Links to relevant online articles and other resources, including:

AAA SITES

AAA Fuel Quality - Gasoline
https://gasprices.aaa.com/fuel-quality

AAA Gas Prices
https://gasprices.aaa.com

GOVERNMENT SITES

EPA List of Registered Diesel Fuel Additives
www3.epa.gov/otaq/fuels1/ffars/web-dies.htm

INDUSTRY SITES

Top Tier Diesel
www.toptiergas.com/diesel-licensed-brands

Power Service Fuel Additives
https://powerservice.com

Endnotes

1 www.bts.gov/archive/publications/bts_fact_sheets/oct_2015/entire
2 https://bit.ly/2WKR3gf
3 www.motor.com/magazine-summary/common-rail-diesel-performance-problems
4 www.nrel.gov/docs/fy02osti/31600.pdf
5 www.epa.gov/diesel-fuel-standards/diesel-fuel-standards-and-rulemakings
6 https://stratasadvisors.com/Insights/022718-11-Countries-Move-Up-In-Top-100-Diesel-Sulfer-Limits
7 https://en.wikipedia.org/wiki/Biodiesel
8 www.dieselforum.org/diesel-drivers/clean-diesel-vehicles-available-in-the-u-s
9 http://iopscience.iop.org/article/10.1088/1742-6596/1095/1/012017/pdf
10 www.betalabservices.com/biofuels/biomass-based-diesel.html
11 www.ethanolproducer.com/articles/15657/innovations-in-biomass-based-diesel
12 www.shell.com/energy-and-innovation/natural-gas/gas-to-liquids.html
13 https://en.wikipedia.org/wiki/Fischer%E2%80%93Tropsch_process
14 www.shell.com/business-customers/commercial-fuels/shell-gtl-fuel/product-benefits.html
15 Scott Grossbauer, Donaldson Filtration Solutions, The Impact of Filter Efficiency on Your Diesel Fuel presentation, SAE Fuel & Lubricants, October 2016, Baltimore, MD
16 www.toptiergas.com/diesel-licensed-brands
17 https://chembloggreen1.wordpress.com/2012/12/13/hygroscopy-and-storage-of-diesel-fuel
18 www.mycleandiesel.com/pages/SolutionMicrobialGrowth.aspx
19 https://powerservice.com/psp_product/bio-kleen-diesel-fuel-biocide
20 www.axi-international.com/mtc-1000-mobile-fuel-polishing-system
21 www.chevron.com/-/media/chevron/operations/documents/diesel-fuel-tech-review.pdf
22 www.youtube.com/watch?v=WdQ4J-NFoU8
23 www.cenex.com/about/cenex-information/cenexperts-blog-page/general-interest/standard-vs-premium-diesel
24 www.sciencedirect.com/science/article/pii/S1876610215013879
25 www.truckinginfo.com/140399/cummins-endorses-two-fuel-additives
26 www3.epa.gov/otaq/fuels1/ffars/web-dies.htm