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Diesel Fuel Quality

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The quality of diesel fuel burned in our vehicle engines may have a profound effect on engine performance, life expectancy and emissions. This report is written as an adjunct to an earlier 2003 document covering gasoline which was updated recently as *Gasoline Quality 2016*. Generally, little factual information is available to the layperson on what affects performance and how the diesel fuel distribution system may cause problems.

In this report, the authors hope to accomplish eight objectives:

- provide a primer on diesel fuel,
- discuss the origins of diesel fuel contaminants and their removal,
- provide information on the effect of contamination on dispensing components,
- provide a primer on current and future biodiesel requirements,
- review issues specific to biodiesel quality and distribution
- provide an overview of today's Clean Diesel technology,
- provide information on fuel consumption in modern diesel engines, and
- discuss special fuel issues for marine, agricultural and other off-road diesel engines.

The first practical gasoline engine was built in Germany by Nikolaus Otto in 1876, an engine operating on a mixture of premixed gasoline with excess air which is introduced into the engine's cylinder(s), compressed and ignited via a spark plug. The first compression-ignited engine was built after the publication of a design concept by Rudolf Diesel in 1893 as a replacement for the rather inefficient steam engines of the day. It required sub-stoichiometric amounts of air and fuel to be injected into the engine's cylinders to be compressed until combustion occurs. It is interesting to note that early diesel engines operated on peanut oil, a biodiesel. While there are many very large diesel engines in marine, railroad and other stationary uses, the emphasis of this report will be on fuels used in on-highway equipment and the accompanying infrastructure.

Diesel Fuel Properties

Diesel fuel is a mixture of hydrocarbons distilled from crude oil containing specified maximum levels of impurities and some minimum level of performance-enhancing additives. The overall characteristics of the blend were traditionally defined by a minimum flash point, maximum distillation temperature and a performance index called a cetane number. Over the last 30 years, efforts to reduce air pollution have extended these definitions to include restrictions on the chemical composition of diesel fuel blends.

In a typical diesel engine, fuel is injected at high pressure into a cylinder of compressed air, where it is compressed until it ignites, then exhausted. The exhaust constituents depend on the completeness of the combustion, which is influenced primarily by engine design, but to some degree by diesel fuel composition. Complete or stoichiometric combustion of a hydrocarbon fuel, including diesel fuel, results in carbon dioxide and water as by-products:

$$C_xH_y + (x + y/4)\ O_2 \text{ -----> } xCO_2 + y/2H_2O$$

where x and y are the numbers of carbon and hydrogen atoms in the fuel.

Since air is used as the primary source for oxygen, secondary reactions occur between nitrogen and other species under the extreme conditions inside the cylinder. Additionally, trace impurities such as sulfur and other incomplete combustion products contribute to the emission of volatile organic carbons (VOCs), nitrogen oxides (NOx) and sulfur oxides (SOx). Since combustion is sub-stoichiometric with respect to oxygen (air) and proceeds at significantly higher pressures and temperatures compared to gasoline engines, uncontrolled VOCs and NOx emissions are higher compared to gasoline and require new treatment methods in order to meet today's emission mandates.

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The majority of the more than 1000 diesel fuel components are alkanes, i.e. saturated hydrocarbons, with 10 to 22 carbon atoms. The balance of diesel fuel consists of cycloalkanes (or naphthenes), alkenes (or olefins) and aromatics, all of which have different combustion characteristics than alkanes, and some polynuclear aromatics (PNAs), which are high boiling and the source of some residues and gums.

In 1993, Federal regulations mandated the reduction of sulfur contained in on-road diesel fuel to 500 parts per million (ppm) or less, reducing SOx emissions by 90% compared to prior diesel specifications which allowed up to 5000 ppm sulfur content. Current rules (2006) have reduced the sulfur level to 15 ppm, reducing SOx emissions further and allowing more effective operation of catalytic exhaust treatment devices that reduce particulates (soot) and NOx emissions. European mandates have reduced sulfur levels even lower to 10 ppm. The refining operations that remove sulfur (principally hydrode-sulfurization) had some unintended consequences: finished ultra-low sulfur diesel fuel reduces swelling of butyl-nitrile rubber seals, reduces lubricity between metal parts in fuel pumps and fuel injectors which are wetted by diesel fuel, and reduces the fuel's conductivity. These effects have been mitigated in modern engines and current dispensing equipment by use of seals made from higher performance (e.g. fluorocarbon) elastomers and added specifications for minimum lubricity and conductivity of diesel fuel. Typically, low levels of additives are used to meet the minimum lubricity and conductivity specifications.

Diesel fuel specifications are set by regulatory agencies and must conform to industry standards established in ASTM D975 (ASTM: American Society for Testing and Materials). These specifications ensure that safety and performance are met by specifying flash point, distillation, combustion characteristics through cetane ratings, maximize product stability and minimize its corrosiveness. Following is a short description of the primary specifications:

Volatility Properties include flash point and maximum distillation temperature. A high flash (125 °F) point ensures that the vapor space above the diesel fuel will not ignite under typical conditions. The distillation of the diesel fuel must meet a specified temperature range for its 90% evaporated fraction, limiting the amount of very high boiling components while keeping the overall diesel fuel characteristics compatible with diesel engine design.

Startability (Cetane number) defines the ease of auto-ignition or ability of diesel fuel to ignite in the engine cylinder. The cetane number is determined by operating a standard test engine having capability of variable compression ratio on the test diesel fuel. The lowest compression pressure needed to ignite the test fuel is compared to operation of the standard test engine on two defined compounds: n-hexadecane ($C_{16}H_{34}$) with a defined cetane number of 100 and 1-methylnaphthalene ($C_{11}H_{10}$) with defined cetane number of 0. Mixtures of these two compounds define the range of cetane numbers for actual diesel fuels; a test fuel with cetane number 40 ignites at the same compression ratio as a 40:60 mixture of n-hexadecane:methyl naphthalene. In practice, due to limited availability, instability and handling difficulty of 1-methylnaphthalene, 2,2,4,4,6,8,8-heptamethylnonane ($C_{16}H_{34}$) with defined cetane number of 15 is used in the test engines instead. The cetane number engine test protocol ASTM D613 is rather cumbersome which has led to the adoption of the ***calculated cetane index*** which is calculated from physical properties of the test diesel fuel, such as density and distillation properties, by a formula that has been correlated with test results from the standard engine tests.

A higher cetane number diesel fuel will ignite at lower compression ratio than a lower cetane number diesel fuel. Since the temperature of the compressed air in the engine cylinder depends on the ambient air temperature and the compression ratio, starting an engine at low ambient temperature is easier with higher cetane number fuel. A minimum cetane number of 40 is specified to give good starting temperatures as low as freezing. For very low temperature starting, engines often are equipped with glow plugs to aid starting. The glow plugs act as the diesel fuel ignition source until the engine is warmed up.

It is important to recognize the fundamental difference between cetane measurements for diesel fuel and octane numbers for gasoline: the former measures the ability for auto-ignition while the latter measures the resistance to auto-ignition. Both numbers define the most important performance characteristics for their respective fuels.

While volatility and cetane represent the parameters most important to motorists, other requirements in ASTM D975 cover additional operational and potential quality issues: controls on *Stability*, *Viscosity, Pour Point, Low-Temperature Operability, Water and Sediment* are designed to meet minimum physical properties that allow the engine and its fuel system to operate; *Copper Strip Corrosion, Lubricity, Ash, Conductivity, Ramsbottom Carbon* residue, and *Sulfur* content are designed to limit corrosion and long-term adverse impacts on the performance of fuel injectors and exhaust treatment devices. ASTM D6751 provides additional specifications for biodiesel fuel blend stock (B100), while ASTM D7467 lists specific requirements for diesel-biodiesel blends between 6-20%.

Diesel Fuel Contamination

Diesel Fuel Distribution

The great majority of diesel fuel today is blended at refineries to diesel transportation fuel specifications and shipped to distribution terminals via pipelines or on barges. From the terminal, it is delivered via tank truck to the service station. If biodiesel is used, it will be blended at the terminal truck rack during loading. Since the pipeline system carries other fuels, particularly jet fuel, biodiesel-containing fuels may not be shipped currently via common carrier pipeline to prevent contamination of other fuels. Because biodiesel is blended at the terminal truck rack during loading, various levels of biodiesel blends can be found at service stations, but generally only one biodiesel level is found at a particular station. While biodiesel levels of 5% and 10 or 11% up to 20% may be found in the distribution system, only blends containing less than 5% are covered by ASTM D975. Biodiesel diesel fuel blends are often designated by their biodiesel content as “Bxx”, e.g a 20% biodiesel blend is named “B20”.

Most diesel fuel is fungible, or interchangeable; while a terminal may supply the same base diesel fuel to different branded outlets, specific brands may be differentiated by addition of the lubricity-stability-conductivity additive package for that brand at the truck rack. Terminal rack blending operations have become quite sophisticated by providing automated additive injection and data logging for many different additives. At the station, product is generally dropped into underground storage tanks. Each tank contains a submersible pump which delivers the specific product to each dispenser. The final quality assurance step is a cartridge filter for each product in most dispensers at service stations. These filters are designed to minimize the possibility of water and solids reaching a vehicle tank.

Origins of Fuel Contamination

Some of us may have experienced or know someone who has experienced problems which can be related to the fuel. A typical problem is fuel filter plugging at extremely low temperatures that prevents the engine from starting or does not allow the engine to develop full power. This type of problem is very rare if diesel fuel specification for the lowest operating temperature (10% lowest monthly) is met. However, more frequent problems result from water or solids reaching a customer’s vehicle tank.

Product contamination may actually start at the refinery. A number of refinery processes require a neutralization step which may result in occasional carryover of caustic. If small amounts of caustic are carried over into the product, they may react with biodiesel or additives and form solids which can appear as gray/black particles or a waxy slime which deposits on dispenser or vehicle fuel filters, or other types of solids.

Shipping products via barges or pipelines may also result in contamination. Barge compartments are generally fabricated of steel. The humid environment can cause rust when empty. Additional problems may occur when ballast water admitted to the product compartments for leveling the vessel is not properly removed prior to loading petroleum products. Pipelines may experience occasional water or settling of solids within the pipeline. When pressure drops increase, operators may send a solid plug, known as a pig, up the pipeline in order to remove the obstruction. The fate of contaminants produced depends entirely on the amount of care exercised when cutting product streams at the nearest terminal tank.

A different set of problems manifests itself as a source for contaminants at terminals. Most terminal tanks today are large diameter steel vessels which may or may not have a floating roof. When a roof is down, the steel walls above are exposed to the atmosphere and rust. Water from condensation or leaks may also accumulate on the floating roofs. The edges of the roof are sealed to the sidewall via seals made of fuel resistant materials. As the roof moves up and down, small particulates are formed from abraded seal material, rust and water and find their way into the product. While non-floating roof tanks eliminate the fines-producing problem, they do represent their own potential for water and contaminants to enter the tank.

The last area for creating contamination is the station storage tank. Steel tanks may experience rust formation in the vapor space. Particulates may also enter through drain valves in spill buckets. In warmer climates, soil particulates may introduce microbes into the tank, which generally thrive in any existing water-product interface and produce additional contaminants. Product delivery into station tanks is via drop tubes to the bottom of the tank, providing vigorous agitation during each delivery. If contaminants are present they may experience sufficient shear to form emulsions with long settling times.

The generation and accumulation of particulates and water in the distribution system that are transferred to other locations is the primary sources of distribution system contaminants. In addition, free water present at the bottom of storage tanks, at low points along pipeline routes or along the bottom of pipelines themselves, can promote microbial activity that often can result in increased corrosion and particulate generation. If biodiesel is present in the fuel, water can have a more pronounced effect on the diesel fuel. Water is more soluble in a biodiesel blend as compared to a petroleum-based diesel fuel; dissolved water in biodiesel can lead to hydrolysis of biodiesel, where the molecule is degraded or broken apart, allowing further reactions with other compounds to form salts, soaps or peroxides.

Removing Diesel Fuel Contaminants

Having discussed various scenarios for contaminants to enter the distribution system, how can oil companies, terminal operators and station owners/operators ensure that their customer is receiving a quality product? The answer is, of course, somewhat obvious: attention to detail by eliminating the source whenever possible or removing the contamination if the source cannot be eliminated. Little can be done about the particulate generation process in terminal tanks. However, the product can be filtered prior to loading into tank trucks. Periodic cleaning of tanks and tank bottoms water management minimizes the problem. At the station, attention to detail is again the key to success. Keeping spill buckets clean and periodically cleaning tanks will minimize contamination. The last line of defense is the dispenser filter, which must be maintained and changed periodically to ensure high flow rates and continued customer satisfaction. Something which should never occur is that owner/operators of stations replace filter cartridges with blanks if repeated plugging occurs.

Modern diesel engines with high pressures common rail fuel delivery systems and very tight tolerances have been experiencing erosion and wear of the injector systems in the presence of fuel particulates. Diesel automotive manufacturers have recommended more stringent particulate limits for diesel fuel specifications through ASTM and are now promoting 10-micron porosity dispenser filters for all products at retail facilities and 30-micron porosity filters for high flow diesel systems such as those found at truck stops, all in an effort to ensure cleaner diesel fuel to the end user.

Dispensing Equipment Problems

If contaminants are allowed into the dispenser piping, serious problems are inevitable. The most immediate problem is the potential of plugging a customer's fuel filter or injectors. However, at the station contamination can manifest itself in other equipment failures which may become expensive to repair and can affect the station's safe operation. One of the more expensive items to repair or replace in a dispenser is the product meter. Depending on the degree of contamination, its operation may become erratic or it may stop working.

The effect of contaminants on hanging hardware, i.e. hoses, nozzles and breakaways, is less predictable. The potential of coating inside surfaces with deposits may lead to corrosion, pitting of the surfaces and deterioration of seals. In the extreme, serious contamination may result in failure of some components. The industry has experienced recurring malfunctions of breakaways failing open rather than closed when accidentally separated and nozzles that fail to shut off. Specific issues with potential effects of biodiesel are discussed in a later section.

One very important safety item resulting from contaminated dispenser filters is often overlooked: dispensing nozzles require a minimum flow rate of product and may fail to shut off when the flow rate drops below the minimum necessary. Any potential fuel spill will result in a safety as well as environmental hazard.

Biodiesel Mandates

There are two main types of biofuels used for diesel fuel blending: fatty acid methyl ester (FAME) and renewable diesel fuel, also known as biomass-based diesel (BBD) under Federal regulations. FAME was the first type introduced into the market place and is based on vegetable oils that are converted to methyl esters by reaction with methanol or, to a very limited extent, ethanol. With relatively high molecular weights, vegetable oils (tri-esters of glycerin) do not burn efficiently in a diesel engine and are converted to the better-performing methyl esters with a single fatty acid group. FAME was introduced to help mitigate the effects of the oil embargoes of the 1970s. Renewable diesel fuel is also produced from vegetable oils, but is produced by a hydrogenation process which produces a non-oxygenated product. Since renewable diesel is composed only of hydrogen and carbon, it is very similar to crude-based diesel fuel in its physical and combustion properties. It is not uncommon for renewable diesel to be produced in a petroleum refinery by co-processing vegetable oil with a refinery stream in a hydrogenation unit. The near equivalence of renewable diesel with petroleum derived diesel fuel makes its use a non-issue for the motorist. The 2014 production of FAME, the predominant renewable diesel fuel, was 1.35 billion gallons with 0.28 billion gallons of renewable diesel.

The Renewable Fuel Standard (RFS) established by the Energy Policy Act of 2005 mandates blending renewable fuels into diesel fuel. The Energy Independence and Security Act of 2007 (EISA) substantially expanded the renewable fuels mandate (RFS2) and incorporates specific biofuel categories. Under RFS2, the total blending requirement for refiners increases each year from 10 billion gallons in 2009 to 36 billion gallons of renewable fuel in gasoline and diesel by 2022. While RFS2 mandates volumes of renewable fuels, it does not authorize new fuel formulations or mandate changes to vehicles. Most vehicles on the road in the U.S., as well as the retail and distribution infrastructure, have been designed for compatibility with 10% ethanol blends (E10) in gasoline and 5% FAME (B5) in diesel fuel. RFS2 leaves resolution of potential conflicts between increasing biofuel requirements and infrastructure compatibility to the market place. The recent (FR 77420, 12/14/2015) Federal mandates for BBD by year are shown in the table below:

BIODIESEL BLENDING REQUIREMENTS

RFS year standard	2015	2016	2017	2018*
Biomass-based diesel, billion gallons	1.73	1.90	2.0	2.1
% in diesel fuel	3.0	3.3	3.6	

*proposed rule making May 2016

While the Federal RFS rules are applied to the aggregate of diesel fuel across the USA (except Alaska), some states/localities have mandated levels of biodiesel that are higher than the average shown above. For example, Minnesota mandates B10 (10%) biodiesel blend for the months April through September and B5 (5%) biodiesel for the remaining months of the year for all diesel fuel sold in the state. On May 1, 2018 the April through September B10 mandate will increase to B20, a 20% biodiesel blend. While not mandating higher biodiesel content, Illinois eliminated the State Sales Tax on all sales of biodiesel blends greater than 11%. As a result, most retail stations in Illinois sell B20 during the summer period.

What does all this mean to the motorist? It is clear that biodiesel use will increase in the coming years. State and local mandates can increase the available biodiesel content of diesel fuel to a level where it exceeds the available blending pool at the 5% accepted by all major diesel vehicle OEMs. Several states have already increased their mandates to B25 by 2025. While some OEMs have introduced vehicles that are compatible with higher levels of biodiesel such as B20, not all have; vehicle owners' manuals generally indicate the types of fuel compatible with their specific engine and provide warnings as to potential warranty problems should a higher diesel fuel blend be used. We will provide additional information on potential vehicle problems in the section on Clean Diesel Technology.

With the increased sophistication of modern engine management systems comes the ability to effectively utilize a wide range of fuels. However, there is limited ability in some current systems for feedback between the engine management system and actual engine performance on a particular fuel. Thus it is important that the minimum cetane specification is met. Vehicle manufacturers program their vehicles to assume the minimum cetane in the country where the vehicle operates (e.g. 40 in the USA or 51 in Europe).

Biodiesel (B100) used as a blend stock for on-highway diesel must meet the quality specified by ASTM D6751 since most states have adopted the ASTM standards as legal requirement. The specification controls physical and combustion properties and sets the minimum required cetane level at 47 for biodiesel, ensuring that blends with hydrocarbon diesel fuel will be at least 40 cetane. The flash point minimum is 199 °F (93 °C) which is higher than diesel fuel, thus maintaining blend safety. Two grades of B100 are defined based on cold temperature performance: Grade 1-B has better low temperature properties as defined by the cold-soak filtration time (200 seconds max) and maximum mono-glyceride (0.40%) content while Grade 2-B has low temperature properties consistent with an earlier version (before 2012) of the B100 specification.

Quality of biodiesel blends is defined by three standard specifications: since 2008, ASTM D975, the primary diesel fuel specification, has incorporated an allowance of up to 5% (B5) blends since they perform very similar to hydrocarbon diesel fuel. Biodiesel (B100) blend stock properties are provided in ASTM D6751, while ASTM D7467 specifies properties for blends of 6% to 20% biodiesel at various sulfur levels with15 ppm sulfur corresponding to current on- and off-road diesel fuel requirements. The table below summarizes selected properties for diesel, biodiesel and blends up to B20:

SPECIFICATIONS FOR DIESEL BLENDS

ASTM	D975 (up to B5)	D6751 (B100)	D7467 (B6 - B20)
Flash Point (ºC, min.)	52	93	52
Distillation Temperature (ºC, 90% evaporated, max.)	338	360	343
Cetane Number (min.)	40	47	40
Ramsbottom Carbon Residue (10% bottoms, mass %, max.)	0.35	0.05	0.35
Oxidation Stability (hrs, min.)		3	6

An important addition to biodiesel blend specifications is ASTM D7467 which lists oxidation stability requirements not present in ASTM D975. Most of us are well aware of cooking oil becoming rancid over time, a property of vegetable oil fatty acids which are prone to oxidation at ambient temperatures. This degradation process can lead to gum, varnish, and sediment formation which may lead to fuel injectors sticking, fuel injector nozzle deposits, and fuel filter plugging, making the oxidation stability requirement for biodiesel blends an important addition to mandated requirements.

Biodiesel inherently has greater solvency than hydrocarbon diesel fuel; its introduction into previously all hydrocarbon diesel fuel systems has the potential to loosen existing deposits and/or sediment, which may cause fuel filter plugging if they are present in more than trace amounts. The previous section on *Removing Diesel Fuel Contaminants* provides additional information.

A *Biodiesel Handling and Use Guide* issued by the National Renewable Energy Laboratory (NREL) in 2009 makes the following statement regarding biodiesel stability and material compatibility:

B20 may degrade faster than petroleum diesel if oxidizing metals such as copper, bronze, brass, or zinc are in the fueling systems…. Galvanized metal and terne coated sheet metal are not compatible with biodiesel at any blend level…. If filters clog more frequently with B20 than they do with petroleum diesel, the fueling system should be checked for these materials and they should be replaced with biodiesel-compatible parts. Typically, these metals are found in lead solders, zinc linings, copper pipes, and brass and copper fittings. Stainless steel, carbon steel, and aluminum are good replacements.

In addition, the NREL guidance clearly states that materials present in the dispensing system as well as the vehicle must be evaluated for compatibility with biodiesel; the document provides an extensive listing of elastomer compatibility which shows that many of the materials used in legacy equipment are not compatible with biodiesel at elevated concentrations.

Recognizing the potential for equipment and contamination problems with biodiesel, in early 2015 Underwriters Laboratories (UL) issued a new series of four testing standards covering dispensers, fittings, valves and nozzles for biodiesel blends up to 20%. State fire marshals in all domestic jurisdictions require the use of fire codes issued by either the National Fire Protection Agency (NFPA) or the International Code Council (ICC); both organizations require the use of listed (third-party certified) equipment for the distribution of transportation fuels. UL provides such third-party services and its staff along with industry volunteers write and maintain the applicable testing standards. Considering the material compatibility guidance provided by NREL in 2009, it is interesting to note that much of the diesel dispensing equipment present in the Midwest, especially in states with a significant presence of B20 blends, does not appear to have been updated to the new UL requirements.

Clean Diesel Technology

Although not directly related to fuel quality issues, this report would not be complete without a short discussion of today's diesel engine technology. While many of us still remember images of older diesel vehicles and trucks belching clouds of smoke and soot, it is now difficult to distinguish modern diesel engines from their gasoline cousins.

Once the vehicle owner has established the level of biodiesel compatible with his vehicle, the question of fuel quality becomes important for the engine's management system. Let us start by stating that today's engines are much different than those built decades ago. With an objective of minimizing exhaust pollutants and maximizing fuel economy, today's modern engine management systems rely on more computing power than was available to the Apollo Space Program. Tailpipe and crankcase losses have been reduced by more than 99% of their unregulated levels in the 1960s. Modern diesel fuel injection timing and "rate shaping" is controlled by the engine management system. Timing refers to the synchronization between the fuel injection event and the position of the piston in the cylinder, while "rate shaping" controls the number of injection episodes and the quantity of fuel injected in multiple events during a single cylinder compression/ combustion/expansion cycle. A direct injection engine may have three or more injection events; multiple injection strategy provides better control of engine noise, emissions and fuel economy.

The online Diesel Forum (dieselforum.org) has summarized clean diesel technology as follows:

With the introduction of lower sulfur diesel fuel came the ability to use a number of exhaust after-treatment options such as diesel particulate filters (DPF), exhaust gas recirculation (EGR), diesel oxidation catalysts (DOC), and selective catalyst reduction (SCR) with the use of diesel exhaust fluid (DEF) that can be sensitive to the sulfur levels in the fuel.

Selective Catalytic Reduction (SCR) is an advanced active emissions control technology system that injects a liquid-reductant agent through a special catalyst into the exhaust stream of a diesel engine. The reductant source is usually automotive-grade urea, otherwise known as Diesel Exhaust Fluid (DEF). The DEF sets off a chemical reaction that converts nitrogen oxides into nitrogen, water and tiny amounts of carbon dioxide (CO_2), natural components of the air we breathe, which is then expelled through the vehicle tailpipe.

SCR technology is designed to permit nitrogen oxide (NOx) reduction reactions to take place in an oxidizing atmosphere…. The DEF can be rapidly broken down to produce the reducing ammonia in the exhaust stream. SCR technology alone can achieve NOx reductions up to 90 percent.

The combination of DPF, EGR and DOC with SCR (also known by various trade names such as AddBlue or BlueTec) has resulted in diesel technology which has reduced emissions compared to gasoline engines and has been certified in all 50 states. The DPF is a catalyst filter that traps particulates and burns them off passively during normal driving or actively during a "self-clean" regeneration cycle. The active regeneration "self-clean" occurs when filter soot loading reaches a predetermined level; the fuel injectors squirt some fuel into the engine cylinders after combustion (post combustion injection) which travels to the oxidation catalytic converter, oxidizes and raises exhaust temperatures to around 600-650°C and burns the trapped particulates in the DPF.

One potential problem with elevated biodiesel blends, which have higher boiling constituents, is that fuel injected during post combustion may not completely vaporize. It may subsequently accumulate in and dilute the engine oil. With some SCR systems, an extra injector in the exhaust injects the post combustion fuel downstream of the engine instead of into the engine cylinders; the additional higher boiling components of biodiesel may contribute to additional ash formation and premature plugging of the DPF. It is interesting to note that passenger diesel vehicles generally have DPFs which must be replaced when plugged, those found on trucks may be serviced.

Vehicle Fuel Consumption

Fuel consumption, especially a comparison between EPA listed data and actual on-road performance, is a mystery to most drivers and often associated with the quality of the fuel. However, first it is important to recognize the fundamental reason for using diesel technology: compared to gasoline, the fuel has a higher energy content and engines operate at higher compression pressures and temperatures, increasing overall engine efficiency significantly. The end result is generally a vehicle with better, or at least similar, performance but up to 40% lower fuel consumption compared to gasoline powered engines. It is interesting to note, that while many motorists never achieve EPA-published fuel consumption rates in their gasoline vehicles, the opposite is true for diesel-powered cars: the automotive press generally reports test results for diesel cars which exceed the EPA mileage estimates.

Fuel consumption data provided to the motorist by the vehicle sales sticker is based on well-defined driving cycles using fuels blended to defined specifications as listed on EPA's website:

Testing vehicles in controlled laboratory conditions establishes a level playing field for all cars and ensures that the test results are consistent, accurate, repeatable, and equitable among different vehicle models and manufacturers. Vehicles are driven on a dynamometer (a device similar to a treadmill) using five standardized driving patterns or test cycles. These test cycles represent a variety of driving conditions including speed, acceleration, braking, air conditioning use, and ambient temperatures. The test results from the five driving cycles are combined to yield individual "city" and "highway" values, and a "combined" fuel economy value that assumes a 55% city/45% highway split.

The results of testing vehicles to EPA's specifications are internally consistent but not generally comparable to the experience of day-to-day driving. Actual fuel consumption is a factor of variables such as weather, terrain, vehicle loading, driver behavior, etc., all factors which are difficult to capture in a standardized testing protocol. Individual fuel consumption may vary considerably and is a strong function of driving style.

Biodiesel contains about 11% oxygen in its molecular structure, resulting in a somewhat lower heating value compared to hydrocarbon diesel fuel and an associated reduction in fuel economy estimated to be about 0.5% for B5; 1.2% for B11 and 2.2% for B20. These small differences will be difficult to notice by the typical motorist, especially in view of seasonal variations when winter diesel fuels are generally blended with lower heating value kerosene in order to improve low temperature operation.

Special Fuel Issues: Boats & Power Equipment Engines

Seasonal activity may pose problems to fuel systems of boats and power equipment engines. Everything we have discussed previously regarding contaminant removal, materials compatibility and fuel properties is equally applicable to these applications with one major additional consideration: stability of diesel fuels and biodiesel blends during periods of inactivity. Recognizing the potential biodiesel stability problem as well as the fuel's increased solvency, some marine diesel providers recommend that prior to seasonal storage, fuel systems be emptied and operated on petroleum-based fuels. An additional recommendation is that engine lubrication, as well as oil and fuel filter change intervals be halved. Most engine manufacturers allow the use of biodiesel blends, but limit them to B20 for engines with exhaust filters.

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