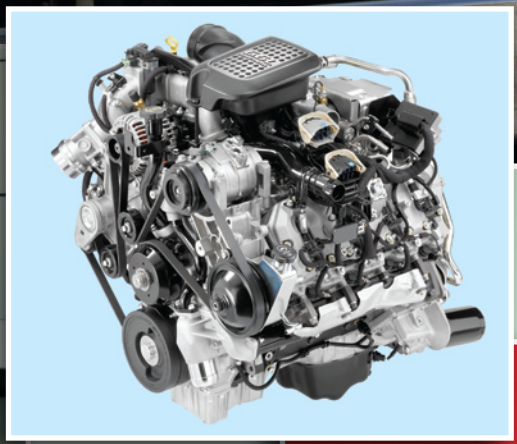
Changes in DIESEL FUEL

SAVE! Important Reference Material

The Service Technician's Guide to Compression Ignition Fuel Quality



Fuel Specifications and Their Relation to Engine Performance

Changes in Diesel Due to Government Regulations

B20

The Latest Information on Biodiesel

Changes In Diesel Fuel
From the Authors of *Changes in Gasoline*

The *Changes in Gasoline* manual series was first introduced in July 1987. Due to continuing changes in gasoline, driven in large part by environmental requirements, the manual has been revised and updated three times over the past twenty years. The focus of the manual series has been to present information about gasoline quality as it relates to vehicle performance and driveability. The manual series is targeted specifically to the service and repair professional who needs a condensed, concise, fuel quality information resource that covers their specific areas of interest. The *Changes in Gasoline* manual series boasts a circulation exceeding 500,000 copies, with a new edition to be released soon.

Over the years we have received numerous requests for a companion manual on diesel fuel quality. In recent years there has been an increasing amount of environmental regulations that impact both the diesel engine and the fuels that power them. These changes have led to our decision to finally write and release *Changes in Diesel Fuel - The Service Technician's Guide to Compression Ignition Fuel Quality*.

We encourage you to read on and see why we believe that, similar to *Changes in Gasoline*, this manual will become the service and repair industry's definitive guide to diesel fuel quality.

Engine and vehicle manufacturers' positions and recommendations can change. Regulations and fuel standards can also change over time. The information contained in this manual was current as of the publication date. The reader is advised that they should verify information to determine if it is still correct.

The use of manufacturer-supplied photos or illustrations does not imply an endorsement of this manual. Likewise, the mention of brand names or products does not imply an endorsement of those products.

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Changes in Diesel Fuel

The Service Technician's Guide to Compression Ignition Fuel Quality

Introduction

For a number of years now there has been an ever-growing list of governmental regulations to address concerns about the environment and dependency on foreign oil. Initially many of these regulations were focused on gasoline-powered automobiles and the fuel that powers them.

More recently there has been a growing list of regulations that require reduced emissions from diesel engines. In addition, regulations for cleaner diesel fuel have been adopted to both reduce emissions and to enable technologies that, while reducing emissions, require cleaner fuels to function properly. Recent concerns related to petroleum use and greenhouse gas emissions are also influencing state and federal policies and regulations.

The Clean Air Act has been the driving force for these changes. The first Clean Air Act was adopted in 1963 and was amended in 1967, 1970, 1977, and most recently in 1990. The first federal emissions requirements for diesel-powered vehicles were in 1971 (1969 in the case of California regulations). Since that time there has been ever-tightening diesel engine emission standards as well as requirements for cleaner diesel fuels. In fact, by the late 1990s, the emissions of a new model heavy-duty diesel truck were about 10 percent for particulate matter (PM) and 27 percent for oxides of nitrogen (NO_x) compared to similar pre-control era diesel trucks. But additional emissions reductions were required. The most recent emissions reductions are very stringent and require more dramatic technological advances in emissions control technology. In order to operate properly, these more advanced technologies require diesel fuel with ultra-low sulfur levels.

While various regulations limit certain fuel properties to meet environmental objectives, there are also specifications that control the performance properties of diesel fuel to ensure that it performs satisfactorily across a broad range of engine applications, with a broad range of uses and duty cycles. In the case of the U.S. fuels market, such guidelines are established by ASTM International.

Environmental issues are not the only thing driving changes in diesel fuel. Energy security also plays a role. Our growing dependence on foreign crude oil and imported transportation fuels has revived interest in renewable fuels including "biodiesel." The Energy Policy Act of 2005 contained a "Renewable Fuels Standard" which requires that a growing amount of our transportation fuels must be renewable fuels such as biodiesel and ethanol. This has resulted in the increased use of biodiesel as a blend component of diesel fuel.

Increasingly the diesel vehicle operator turns to his service shop for fuel-related information and advice. Questions often focus on the type of diesel (sulfur level), on-road grades versus off-road, premium diesel, cetane ratings, use of over-the-counter additives, and biodiesel. But it is often difficult for the service technician to obtain factual information written with the service shop in mind. This is, in part, because only a few years ago this information was considered "nice to know" but not "need to know." That has changed, and today it is important for the diesel service and repair technician to understand diesel fuel quality issues, both for diagnostic reasons and to have the ability to provide accurate information to the vehicle or equipment operator.

This manual is designed to aid in that effort. Fuel specifications and their relationship to vehicle performance are covered. Changes in fuel composition are discussed in detail. The impact of government regulations on diesel fuel composition are also discussed. Due to its recent expanded use in the marketplace, biodiesel is also covered.

Like its sister publication, *Changes in Gasoline*, this manual is designed to separate fact from fiction. It is based on numerous technical references, primarily from diesel engine and fuel system manufacturers, and the petroleum industry. It is designed to aid you in identifying any fuel-related problems and to also assist you in explaining fuel issues to your customers. Although targeted to the service and repair community, others may also find this manual useful in discussing diesel fuel issues with consumers.

It is our hope that this information will prove to be a useful shop reference for diesel fuel information.

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Chapter 1: Diesel Fuel Quality – Standards, Specifications and Additives

In order to understand fuel quality standards and how they affect diesel engine performance, it is important to have a basic understanding of diesel fuels, how and why quality standards are set, and how these standards relate to the operability, performance, emissions, fuel economy and durability of a diesel engine and related systems.

ASTM Specifications

Diesel fuel comes in several different grades, depending upon its intended use. Like gasoline, diesel fuel is not a single substance, but a mixture of various petroleum-derived components, including paraffins, isoparaffins, napthenes, olefins and aromatic hydrocarbons, each with their own physical and chemical properties. Diesel fuel must satisfy a wide range of engine types, differing operating conditions and duty cycles, as well as variations in fuel system technology, engine temperatures and fuel system pressures. It must also be suitable for a variety of climates. The properties of each grade of diesel fuel must be balanced to provide satisfactory performance over an extremely wide range of circumstances. In some respects, the prevailing quality standards represent certain compromises so that all the performance requirements may be satisfied. By controlling specifications and properties, it is possible to satisfy the requirements of millions of compression ignition engines with a single grade of diesel fuel. The most commonly used guidelines for diesel fuel quality are established by ASTM International. ASTM specifications are established by consensus, based on the broad experience and close cooperation of producers of diesel fuels, manufacturers of diesel engines and fuel systems (and users of both), as well as other interested partners such as state fuel quality regulators. Often ASTM turns to organizations such as SAE International and the Coordinating Research Council to produce reliable technical data to aid in the development of fuel specifications. ASTM standards are continuously reviewed and updated when the need arises.

ASTM standards are viewed as voluntary compliance standards, although Federal and State regulations often require diesel fuels to meet all, or a portion of, ASTM specifications.

The ASTM standard for diesel fuels is "ASTM D 975 – Standard Specification for Diesel Fuel Oils." This standard currently covers seven grades of diesel fuel oils. These grades include numbers 1-D (S15), 1-D (S500), 1-D (S5000), 2-D (S15), 2-D (S500), 2-D (S5000) and 4-D. The grades are listed in order of increasing density and viscosity. In other words, a 2-D grade is denser and of higher viscosity than grade 1-D. The parenthetic numbers such as (S15) refer to the maximum sulfur level for the grade. Thus 2-D (S15) refers to No. 2 diesel with a maximum of 15 parts per million (ppm) sulfur. Grades designated S500 are low sulfur diesel (maximum 500 ppm sulfur), while S15 designates ultra-low sulfur diesel. The S5000 grades, as well as No. 4-D, are for off-road use only. (Note that off-road grades or on-road grades sold for off-road use are required to contain a red dye so that they can be easily identified for taxation purposes.) Although all of these grades are technically diesel fuel oils, in the U.S. when the word diesel fuel is used, it is primarily in reference to No. 2-D grades, since that is the grade generally used in all on-road vehicles as well as the majority of off-road applications. Grade No. 2-D is also the focus of this manual.

In addition to the property limits in ASTM D 975, numerous test methods are encompassed in the specification to accurately measure the specified properties. While the ASTM standards ensure acceptable fuel quality, some petroleum companies and pipeline operators may require more stringent standards. In addition, SAE International Surface Vehicle Standard J 313 – Diesel Fuels, provides diesel fuel quality guidelines and the Engine Manufacturers Association (EMA) also stipulates certain fuel quality parameters. Other countries may rely on ASTM D 975 while some, such as European countries and Japan, have their own standards which may vary slightly from the ASTM property limits.

The aforementioned standards focus primarily on standards related to engine performance. There are

also federal, and in some cases state, specifications that focus on the environmental impact of diesel fuel. While compliance with these specifications is required, diesel fuel should still meet the standards established by ASTM.

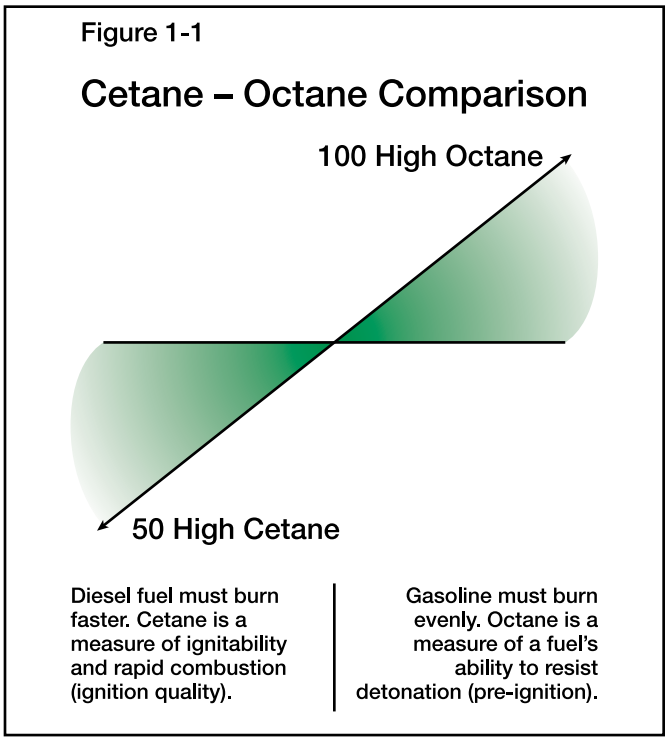
The intent here is to tie all these standards together and relate them to performance. In order to make the manual more reader-friendly, some technical issues are represented in non-technical terms so the reader is not burdened with unnecessary chemistry and engineering topics.

Cetane Quality

Probably the most familiar diesel fuel property to end users and the service and repair professional is ignition quality, as expressed by cetane number.

Cetane number is a measure of the ignition quality of the fuel. Cetane number affects combustion roughness. Consumers often think the cetane number is similar to the octane number for gasoline, but that is not the case. Octane is a measure of a spark ignition engine fuel's (gasoline) ability to resist engine knock (pre-ignition from compression). Diesel cetane ratings work in the opposite direction. The higher the cetane rating, the more easily it ignites. Reaching desired cetane levels also limits the aromatic content of diesel fuel.

Figure 1-1



Diesel fuel cetane ratings are calculated by calibrating a fuel to a mixture of reference fuels in a specially designed Cooperative Fuel Research (CFR) engine.

Acquisition and operating costs for a CFR engine are expensive, and it is not the easiest test to perform. Various tests have been developed to calculate the cetane number from certain fuel properties. These tests usually involve some combination of fuel density and distillation properties. The two more commonly used cetane number estimate formulas are referred to as cetane indexes to distinguish their results from the engine test. The most common cetane indexes are ASTM D 976 and ASTM D 4737. There are other cetane index methods that incorporate various fuel properties, but they are not as widely used as the ASTM methods. One problem with cetane indexes is that they report the cetane index number of the fuel. If cetane improver additives have been used in the fuel, it will raise the cetane number of the fuel, but this will not be adequately reflected in the cetane index calculation.

Cetane number requirements of an engine will vary depending on engine size, speed and load variations, starting conditions and atmospheric conditions.

Since a diesel engine ignites the fuel without a spark, proper cetane levels are very important. The air/fuel mixture is ignited by the combination of compression and heating of the air due to compression. The fuel is injected into the cylinder at the precise time ignition is desired to optimize performance, economy and emissions.

While gasoline engines time the spark to ignite the fuel, a diesel engine controls ignition by the injection of the fuel using either mechanical injectors or, more recently, by electronically controlled fuel distributors and individual injectors. This also necessitates much higher fuel pressures to overcome the pressure in the combustion chamber during the compression stroke. More simply put, in a spark ignition engine the amount of air is changed to control speed and power, while in the diesel engine the amount of air remains constant while the amount of fuel is varied. Diesel engines can operate at very lean mixtures when idling (e.g., 80:1) or move to richer mixtures during high load conditions (e.g., 20:1).

Given the operating conditions, it is easy to see why cetane level is important. In addition to improving fuel combustion, increasing cetane level also tends to reduce emissions of nitrogen oxides (NO_x) and particulate matter (PM). These emissions tend to be more pronounced when starting with lower cetane number fuels. Increasing the cetane number value above that required for a given engine may not, however, improve engine performance. Some tests have shown that excessively high cetane number fuels may cause smoking (higher PM emissions).

The minimum cetane number for diesel fuel (Grades No. 1 and 2) is 40. The fuel should also meet a minimum cetane index of 40 or, alternatively, contain no more than 35 volume percent aromatics. Some manufacturers may recommend higher cetane number fuels, so the vehicle or equipment owner's manual should always be consulted.

Table 1-1

Results of Inadequate Cetane Number
Poor Ignition Quality
Long Ignition Delay
Abnormal Combustion
Abnormally High Combustion Pressure
Potential Uneven Thrust on Piston / Cylinder
Louder Engine Knock
Excessive Engine Knock & Smoke at Cold Start

Volatility

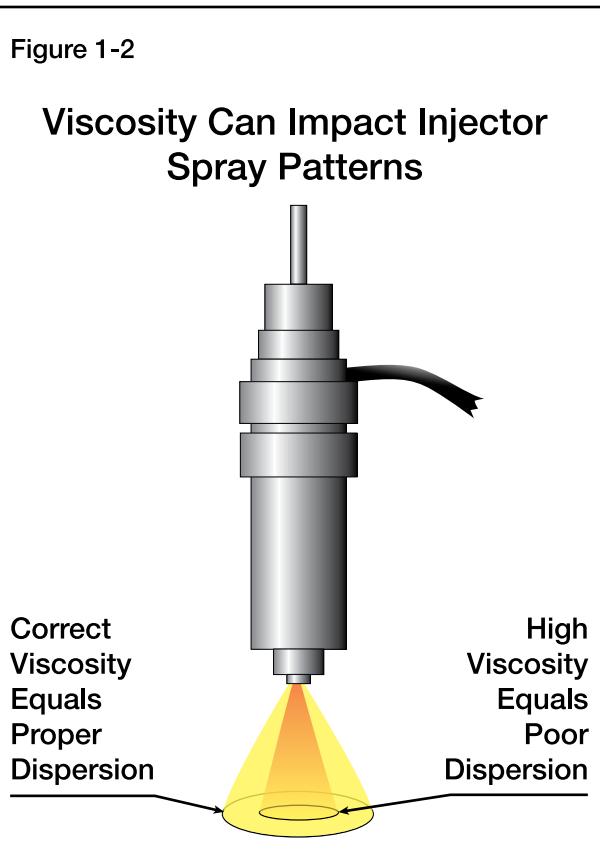
Unlike spark-ignition engines, the power and economy of diesel engines are comparatively insensitive to fuel volatility. There is some indirect impact in that less volatile fuels have higher heating values (energy content). Conversely fuels with higher front-end volatility tend to improve starting and warm-up performance and reduce smoke.

Ideal fuel volatility requirements will vary based on engine size and design, speed and load conditions, and atmospheric conditions. As an example, more volatile fuels may provide better performance for fluctuating loads and speeds such as those experienced by trucks and buses. ASTM D 975 only sets a minimum/maximum range for the temperature at which 90 percent of the fuel will evaporate. This is referred to as T_{90}, and the range for No. 2 grades of diesel fuel is 282°C to 338°C. This limits the level of high boiling point components that could lead to increased engine deposits.

Viscosity

The viscosity of diesel fuel is an important property which impacts the performance of fuel injection systems. Some injection pumps can experience excessive wear and power loss due to injector or pump leakage if viscosity is too low. If fuel viscosity is too high, it may cause too much pump resistance, filter damage and adversely affect fuel spray patterns.

Figure 1-2



High fuel viscosity can cause an injector spray pattern with poor fuel dispersion.

In general, fuels with low viscosity tend to have poorer lubrication properties.

ASTM D 975 requires a kinematic viscosity range of 1.9 minimum to 4.1 maximum mm^2/S at 40°C, for No. 2 diesel fuels (note that the term mm^2/S replaces the former term of centistokes [cst]).

Carbon Residue

A carbon residue test is performed to approximate the engine deposit-forming tendency of diesel fuels. In the ASTM specification, this is referred to as the "Ramsbottom Carbon Residue on 10 mass percent Distillation Residue." This number is limited to a maximum of 0.35 mass percent for No. 2 diesel.

Sulfur Content

Engine wear and deposits can vary due to the sulfur content of the fuel. Today the greater concern is the impact that sulfur could have on emission control devices. As such, sulfur limits are now set by the U.S. Environmental Protection Agency (EPA), and those limits have been incorporated into ASTM D 975. For No. 2 grade low sulfur diesel, the limit is a maximum of 0.05 percent mass (500 ppm) and, for ultra-low sulfur diesel, it is 15 parts per million (ppm) maximum.

Flash Point

ASTM D 975 includes a flashpoint requirement. This is not related directly to engine performance. The flashpoint is controlled to meet safety requirements for fuel handling and storage. The flashpoint is the lowest fuel temperature at which the vapor above a fuel sample will momentarily ignite under the prescribed test conditions. For No. 2 diesel grades, the flashpoint is a minimum of 52ºC.

Low Temperature Operability

The cloud point of a diesel fuel is the temperature at which the amount of precipitated wax crystals becomes large enough to make the fuel appear cloudy or hazy. Wax may form because normal paraffins occur naturally in diesel fuel. As the temperature of the fuel is lowered, these paraffins become less soluble in the fuel and precipitate out as wax crystals. In some fuel systems, cloud point can indicate the onset of fuel-filter plugging. Although ASTM D 975 provides a test method for determining cloud point, it does not set a specific temperature. This is because it is impractical to set low temperature properties for all ambient temperatures. Also, depending on equipment design and operating conditions, satisfactory operation may be achieved even below the cloud point. Cloud point and other low temperature operability limits such as low temperature filterability, cold filter plugging point, and pour point are generally specified by contract between the fuel supplier and fuel purchaser, who can best determine the necessary limit based on intended use and anticipated climate.

Pour point is the lowest temperature at which the fuel will flow and is used to predict the lowest temperature at which the fuel can be pumped. As mentioned above, other tests include the "Filterability of Diesel Fuels by Low Temperature Flow Test" (LTFT) and the "Cold Filter Plugging Point" (CFPP) test. One or more of these can help predict a diesel fuel's low temperature operability properties.

Ash

Abrasive solids or soluble metallic soaps may be present in diesel fuel. These ash-forming materials can result in injector and fuel pump wear, as well as piston and ring wear, in the case of abrasive solids, and engine deposits may also increase. The primary concern with soluble soaps is their contribution to engine deposits. ASTM D 975 sets a maximum limit of 0.01 mass percent ash content for both No. 1 and No. 2 diesel fuels.

Corrosion Properties

A copper strip corrosion limit (under specified test conditions) is used to predict possible problems with copper, brass or bronze fuel system components.

Water and Sediment

Because diesel fuel moves through various pipelines and tanks, and in some cases is moved by waterborne vessels, the potential exists for water and sediment to contaminate the fuel. Water and sediment contamination can contribute to filter plugging and fuel injection system wear. These contaminants may also lead to increased corrosion. The ASTM limit for water and sediment in diesel fuel is a maximum of 0.05 percent by volume.

Lubricity

Diesel fuel lubricity is a very important property, since the diesel fuel injection system relies on the fuel to lubricate moving parts. As with low-viscosity fuels, if lubricating properties are inadequate, it will lead to increased wear on injectors and pumps.

In years past, naturally occurring lubricity agents in diesel fuel provided adequate protection. More recently, certain refinery processes such as those used to comply with new low sulfur and aromatics requirements, tend to remove these naturally occurring materials. Lubricity additives are often required to avoid catastrophic fuel pump or injector failures. As little as one tank full of poor lubricity fuels can cause such catastrophic failures.

Current test methods for assessing fuel lubricity continue to be improved. Work on diesel fuel lubricity and the best test procedure to measure wear is ongoing within several organizations, including ASTM. The two most common test methods are the "Scuffing Load Ball-on Cylinder Lubricity Evaluator" (SLBOCLE) test and the "High Frequency Reciprocating Rig" (HFRR) test. The current version of ASTM D 975 specifies the HFRR test method, and the current requirement is a maximum of 520 microns at 60°C (measurement of wear).

For more detailed and accurate assessment, a long-term durability pump test can be conducted. However, these tests are lengthy and expensive and, therefore, usually impractical except for research projects.

Related Properties

Certain properties of diesel fuel tend to be related. For instance, a low-volatility fuel usually has higher viscosity, cetane number and cloud/pour points than higher-volatility fuels.

The actual composition of diesel fuel can differ among refineries, or even between batches produced at one refinery, because of differences in crude oil inputs and other factors. Each component used tends to have somewhat different properties and interrelationships with properties of the fuel to which it is added. This is why the ASTM specifications focus on the performance properties of the fuel rather than exact composition.

Table 1-2

Summary of ASTM Specifications	
Property	**Importance**
Cetane Number	Measure of ignitability (ignition quality), reduce knock and smoke
Cetane Index/Aromatics Limit	Limits aromatic content of fuel to prevent adverse emissions impact, reduce knock and smoke
Volatility	Deposits, wear, exhaust smoke
Viscosity	Injector wear & spray pattern, pump wear, filter damage
Sulfur Content	To protect emissions control equipment
Low Temperature Operability	Flow properties, filter plugging
Water & Sediment Content	Filter plugging, injector wear, increased corrosion
Lubricity	Injector & pump wear
Ash Content	Injector & fuel pump wear, piston & ring wear, engine deposits
Corrosion	Protect copper, brass, bronze fuel system parts
Flash Point	Safety during fuel handling & storage
Carbon Residue	Fuel system deposits, combustion chamber deposits

Other Important Fuel Quality Issues

There are other properties that petroleum companies may monitor and control which are not specified in ASTM D 975.

Gravity/Density

The gravity or density of a fuel, along with other parameters, can be used to indicate certain fuel composition ranges. This information can then provide directional predictions of fuel economy, power, deposits, wear and exhaust smoke. For instance, a diesel fuel with a low API gravity (increased density) contains more energy per gallon (heating value). Such a fuel would tend to improve fuel economy. However, excessively low API gravity could result in increased engine deposits and smoke. Gravity is not the sole determining factor in predicting such performance properties. Gravity is, however, a useful test in the field, since such tests can be done with a hydrometer. Sometimes gravity is expressed as specific gravity. This measurement is the inverse of API gravity. Fuels of low API gravity will have high specific gravities. In the SI Metric System, these measurements have been replaced by absolute density (for API gravity) and relative density (for specific gravity).

Heating Value (Energy Content)

The heating value of a fuel is a measure of the energy content. Energy content can impact the thermal efficiency of producing power. While ASTM does not specify a heating value, this property continues to be of interest to engine manufacturers. The heating value of a fuel can be expressed in a number of ways such as Joules per kilogram (J/Kg), Joules per liter (J/L), and British Thermal Units/per gallon (btu/gal.). The latter is used here, since it is more commonly understood by the service and repair community. However, since diesel fuel consumption may be expressed in kilograms per kilowatt hour (kg/kw-h) or pounds of brake horsepower per hour (lb/bhp-h), measurements on both a weight and volume basis are of interest to the designers and manufacturers of engines. The typical energy content of No. 2 diesel fuel is 130,000 btu/gal. compared to about 114,200 btu/gal. for gasoline. Fuel economy is discussed in more detail later in the manual.

Thermal Stability / Oxidation Stability

Diesel fuel is usually sold within a few weeks to a few months of its manufacture. Thermal stability is known to degrade during storage. Fuels stored for extended periods can contain contaminants, such as peroxides, from the oxidation of the fuel. These contaminants can increase deposits and lacquer buildup in fuel pumps and injectors, as well as increase filter plugging. Manufacturers use an ASTM test method to predict the thermal stability of diesel fuel.

Microbial Contamination

Certain bacteria and fungi are present in diesel fuel tanks. These “bugs,” which feed on hydrocarbons, if left to grow unchecked, can contribute to filter plugging and corrosion as well as other operational problems. Avoidance of microbial contamination can be achieved through proper “housekeeping” techniques and, when necessary, the use of biocides.

Housekeeping and Fuel Handling Procedures

A number of fuel handling and storage procedures are employed throughout the petroleum distribution network to avoid contamination. For instance, keeping storage tanks free of water is very important, because water promotes corrosion. Also, since microbial growth generally occurs at the interface of the diesel fuel and tank “water bottoms,” keeping tanks free of water helps prevent microbial contamination.

Diesel Fuel Additives

There are a number of commercial diesel fuel additives that the petroleum industry may use to meet and maintain diesel fuel properties. It is appropriate to make a few distinctions with regard to commercial diesel fuel additives. Additives and fuel components are not the same. Components add volume to the fuel and fall into hydrocarbon classes such as naphthenes, isoparaffins and aromatics. Additives, on the other hand, are added at very low levels, usually at the parts-per-million level, and do not add significant volume to the fuel. Also, commercially available additives are generally added only when the need to do so has been determined by the fuel manufacturer. This is

as opposed to over-the-counter (OTC) additives, which are added without knowing if there is really a need. While there are always exceptions, OTC additives are of limited use, since the additives are already in the fuel if there is a need for them. There are numerous additives available that are designed to be used in diesel fuel. The US EPA maintains a list of approved additives. Cetane improvers are used to raise cetane numbers and improve ignition quality. The addition of lubricity improvers provides antioxidants, stabilizers and metal deactivators. Biocides may be used to reduce the formation of bacteria and fungi, which helps prevent fuel filter plugging.

In colder temperatures, pour point depressants may be added to improve cold flow properties. Cloud point depressants reduce the temperature at which paraffins (waxes) solidify, thereby lowering the cloud point. In some cases, de-icers may also be used to prevent fuel line freezing.

Figure 1-3

Injector Spray Patterns – Clean versus Deposits

A clean injector such as the one in the photo on the left provides good atomization of the fuel. Once injectors build up deposits, as the injector in the photo on the right, the fuel does not atomize properly.

Courtesy of the Lubrizol Corporation

better lubricity, thereby promoting better lubrication in fuel pumps and injectors. Detergents and dispersants help prevent fuel injector deposits and clean dirty injectors, which promotes better spray patterns.

The diesel fuel injector tip is exposed to very harsh operating conditions which contribute to carbon buildup (injector coking). When this occurs, not only may fuel flow be reduced, but the fuel does not atomize as well.

Several types of additives can be used to inhibit oxidation, thereby reducing formation of gum and precipitates. This extends the storage life of the fuel. This group of additives includes

The use of low temperature operability additives, such as pour point depressants and cloud point depressants, provides an advantageous alternative to blending with No. 1 diesel. In years past, winterized diesel was recommended for subzero temperatures. This was accomplished by blending No. 1 diesel into No. 2 diesel, which would lower the temperature at which the fuel would start to gel, because of the blend's lower cloud point. Unfortunately, No. 1 diesel has a lower heating value (lower btu content per gallon) than No. 2 diesel, so this approach results in a fuel economy penalty and power loss. As an example, a 50/50 blend of No. 1 and No. 2 diesel may reduce fuel economy by nearly 5 percent and result in a power loss of up

to 4 percent (see Figures 1-4 and 1-5) compared to No. 2 diesel.

Figure 1-4

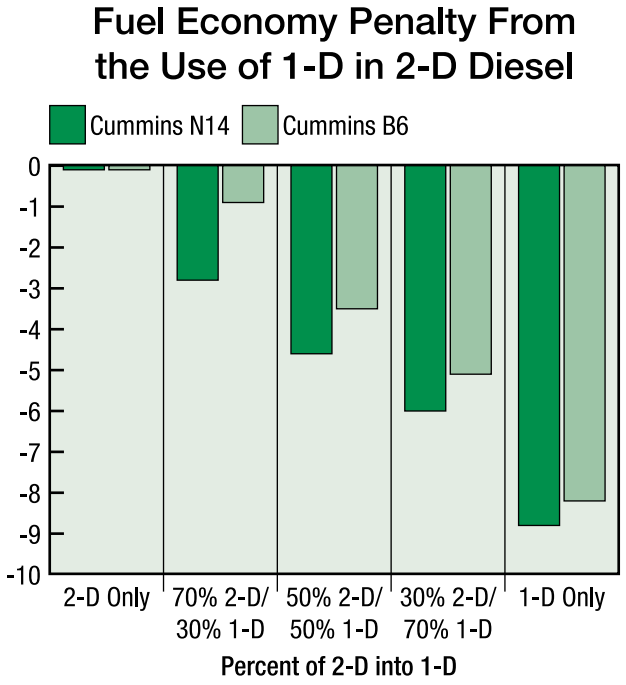
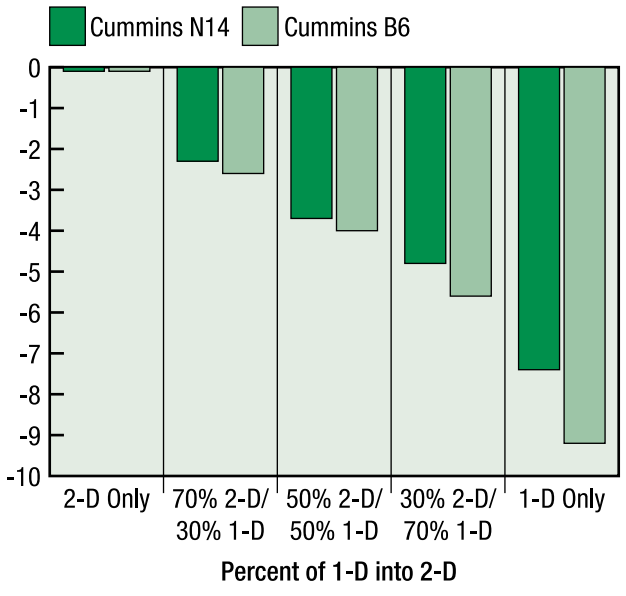


Figure 1-5



Cloud point depressant additives can be used to change the size and shape of wax crystals that form at low temperatures. These alterations allow fuel to more readily pass through the wax that may accumulate in the fuel filter without the reduction in power and fuel economy described above for fuel blending.

Other additives include antifoaming agents to reduce fuel foaming during fill-ups, smoke suppressants which reduce smoke by promoting improved combustion, and rust preventors that are sometimes added to reduce rust formation in fuel systems and in storage tanks. Emulsifiers and dehazers may be used to promote the rate of water separation from the fuel. Finally, certain dyes may be utilized to identify grades of diesel for regulatory compliance purposes.

There are also additives that may be used for reasons other than fuel vehicle performance. Examples of these include antidrag additives, which are used to improve pipeline flow rates, and conductivity improvers, which improve the dissipation of static charge.

Table 1-3 on the following page recaps the common diesel fuel additives and their relevance to vehicle performance and safety.

Premium Diesel Fuel

The growing population of late-model, high-technology diesel vehicles has led to some companies offering a premium diesel fuel.

The ASTM specifications do not specify what constitutes a premium diesel fuel. Premium gasoline is defined primarily by a higher octane number. Many engine manufacturers and state regulators believe a premium diesel fuel requires more than just a higher cetane number. The National Conference on Weights and Measures (NCWM) has adopted standards for premium diesel fuel. These requirements are set forth in the National Institute of Standards and Technology (NIST) Handbook 130, Engine Fuels, Petroleum Products and Automotive Lubricants Regulation. The requirements of the NIST Handbook 130 are model regulations, not federal requirements. However, many states adopt the requirements of the NIST Handbook 130, or use them as guidance in developing their own regulations. Their requirements represent input from fuel manufacturers, engine manufacturers and state regulators. The portion of the regulation applying

to premium diesel specifies that any diesel fuel designated as premium, super, supreme, plus or premier conform to the following:

Cetane Number: Minimum 47

Low Temperature Operability: A cold flow performance measurement which meets the ASTM D 975 tenth percentile minimum ambient air temperature chart and maps by either the Cloud Point Test or the Low Temperature Flow Test. These requirements apply October 31st through March 31st.

Thermal Stability: A minimum reflectance measurement of 80 percent as determined by ASTM Test Method D 6468 (180 minutes, 150ºC).

Lubricity: A maximum wear scar diameter of 520 microns (by ASTM Test Method D 6079 – certain enforcement retesting may be applicable).

The combination of these is meant to ensure that premium diesel provides superior ignition quality and improved low temperature operability characteristics. In addition, the potential for fuel degradation in storage is reduced, and a specific level of lubrication is required. This standard was last amended in 2003. As with ASTM Standards, the NCWM and NIST constantly review their requirements to determine if updates are necessary.

In many states that do not specifically regulate what properties premium diesel should possess, the fuel may only meet one or two of the NIST requirements. However, absent regulations to the contrary, marketers may still designate such fuels a premium grade.

Table 1-3

Type and Function of Diesel Fuel Additives	
Type of Additive	**Function**
Cetane Number Improver	Improves ignition quality by raising cetane number, better starts, reduces white smoke
Lubricity Improvers	Improve lubricity, better injector & pump lubrication
Detergents / Dispersants	Clean injectors, better spray patterns
Antioxidants	Extend storage life, inhibit oxidation, reduce gum and precipitate formation
Stabilizers	Inhibit oxidation & extend storage life
Metal Deactivators	Deactivate copper compounds in fuel, thereby promoting longer storage life
Biocides	Inhibit bacterial & fungi growth, help prevent fuel filter plugging
Pour Point Depressants	Low temperature operability, improve cold-flow properties
Cloud Point Depressants (Suppressants)	Reduce temperature at which paraffins solubilize
De-Icers	Prevent fuel line freezing
Anti-Foam Agents	Reduce foaming when filling tanks
Smoke Suppressants	Promote more complete combustion, reduce exhaust smoke
Rust Preventors	Reduce formation of rust in fuel systems & storage tanks
Demulsifiers / Dehazers	Used to increase the rate of water separation from the fuel
Dyes	To identify types of diesel for regulatory compliance

Chapter 2: Changes in Diesel Engines and Diesel Fuel Driven by Regulations

Over four decades ago, federal regulations began to control the emissions from automotive spark-ignition engines. This necessitated an increasing level of sophistication in fuel systems, engine management systems, and exhaust after treatment. At the same time, it became necessary to modify gasoline to accommodate these more sophisticated systems. More recently, a similar transition has been occurring with diesel engines and diesel fuel.

Environmental Regulations

The EPA set its first limits for emissions from heavy-duty diesel engines in 1971. In 1985, the U.S. EPA adopted stringent emission standards that took effect in 1991 and 1994. In 1990, the EPA imposed limits on diesel fuel sulfur content to help buses and trucks meet these standards. These limits took effect in 1993. Then in 2000, the EPA developed a comprehensive national control program that, beginning with the 2007 model year, regulates the heavy-duty vehicle and its fuel as a single system. The EPA also required a 97 percent reduction in the sulfur levels of 80 percent of on-road diesel fuel in mid-2006. This level will apply to all on-road diesel fuel effective December 2010. It should be noted that the State of California sets its own limits on diesel emissions. They are generally the same as federal requirements, although they are sometimes more restrictive or may take effect at an earlier date than federal requirements. For instance, CARB has controlled the aromatic content of diesel fuel since 1993 but allows alternate formulas to achieve compliance. The exhaust components of interest in diesel exhaust are different than those in spark-ignited engines. Likewise, the units of measurement are different for heavy-duty diesel engine emissions. The regulated pollutants of interest are carbon monoxide (CO), hydrocarbons (HC), oxide of nitrogen (NO_x) and particulate matter (PM). For a diesel engine, CO and HC are fairly low. The primary focus is on NO_x and PM.

Light-duty vehicle emissions of gasoline-powered and diesel-powered vehicles are measured in grams per mile. These units of work are not appropriate for heavy-duty diesel engines. Diesel engines may be used in several different brands of vehicles or equipment. Also, there are much larger differences in the size and loads of diesel engines. In the case of diesel engine emissions, the unit of measure is grams per brake horsepower hour (g/bhp-hr), which provides a single measurement standard applicable for heavy-duty engines of all sizes.

The table below provides an example of the ever-tighter standards on heavy-duty highway diesel engine emissions during the 1990s.

Table 2-1

Historical Federal Heavy-Duty Highway Diesel Engine Emission Standards

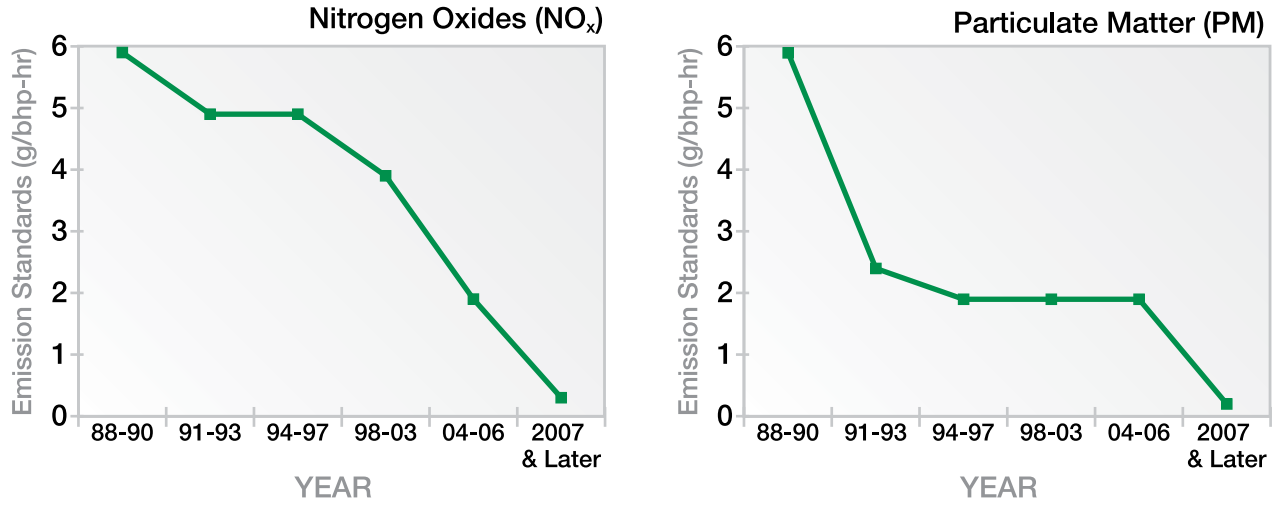
Year	CO (g/bhp-hr)	HC (g/bhp-hr)	NO_x (g/bhp-hr)	PM (g/bhp-hr)
1990	15.5	1.3	6.0	0.60
1991-1993	15.5	1.3	5.0	0.25
1994-1997	15.5	1.3	5.0	0.10
1998+	15.5	1.3	4.0[1]	0.10[2]

1. This standard had to be met by 1996 in California.
2. Urban buses must meet a 0.05 g/bhp-hr PM Standard.

Figure 2-1

United States Heavy-Duty Truck Engine Standards, (GVW>3.5t)

Beginning with the 1988 Model Year



These charts demonstrate the emissions requirements for NO_x and PM for the 1998 through 2012 Model Years.

More stringent NO_x and PM standards were implemented in 2004 and 2007, as depicted in the above figure.

A similar trend exists for light-duty vehicles sold in the U.S. Beginning with the 2004 model year, diesel-powered passenger vehicles were required to meet the same PM and NO_x standards as their gasoline-powered counterparts.

As noted earlier, California often adopts similar or slightly more restrictive standards, or may adopt standards earlier. For instance, the heavy-duty diesel engine NO_x standard of 4.0 g/bhp-hr was adopted by the U.S. in 1998, but it was adopted two years prior to that in California.

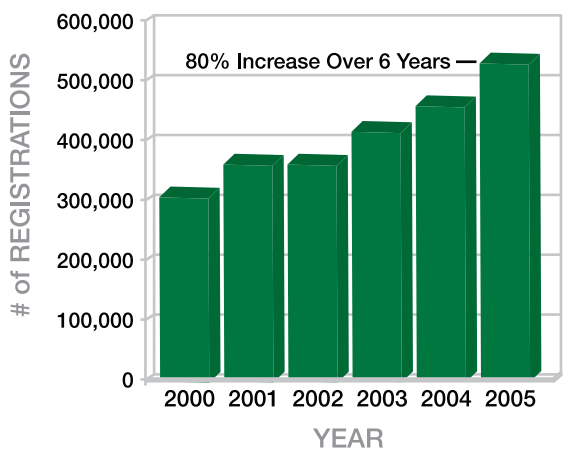
Also important to note is that while this manual focuses primarily on on-highway diesel engines and fuels, emissions standards on off-road diesel engines are also being tightened. In 1997, the EPA finalized emissions standards for new and remanufactured locomotives and locomotive engines. In 1999, the EPA adopted emission standards for new, large marine engines. Similarly, California's Air Resources Board (CARB) has been adopting standards for off-road diesel equipment. In July 2007, CARB announced a rule which will require the addition of soot filters on existing equipment and encourage replacement of older, dirtier engines with newer emissions-controlled engines.

More stringent requirements are forthcoming. Beginning in 2010, the U.S. will require on-board diagnostics (OBD) on heavy-duty truck and bus engines. This requirement will be phased in between 2010 and 2016. The OBD system will monitor all systems and parts that could affect emissions, including the fuel system, catalytic system, EGR and particulate filters.

Past, present and future regulations have all stimulated a dramatic change in diesel engines, fuel systems and after-treatment technologies. Once viewed as dirtier than their gasoline counterpart, diesel engines are receiving renewed attention because, on a unit-of-work basis, diesel fuel emits fewer greenhouse gases than gasoline. Since NO_x and PM have now been lowered dramatically, diesel engines and the fuels that power them can be part of the environmental solution instead of being part of the problem. For instance, a newer model heavy-duty truck, even of 1998 vintage, emits only about 27 percent of the NO_x and 10 percent of the PM of pre-emission-control trucks. A new 2007 diesel truck will emit one-sixth of the soot of one produced in 1998. By the 2010 model year, NO_x emissions will have been reduced by 90 percent compared to the 2004 level.

In the light-duty vehicle segment, the clean and quiet diesel engines that power passenger vehicles have resulted in higher sales of these vehicles in the U.S. Annual registrations in 2005 were up 80 percent compared to those in 2000.

Figure 2-2



Source: R.L. Polk & Company

Strategies for Compliance – Engine Technology

In order to achieve these more stringent standards, the diesel industry has had to focus on several strategies to achieve compliance. Initially, this effort focused on better management of fuel flow and the combustion process. The strategies vary somewhat between passenger vehicles (light-duty) and large trucks (heavy-duty) due to different emission standards.

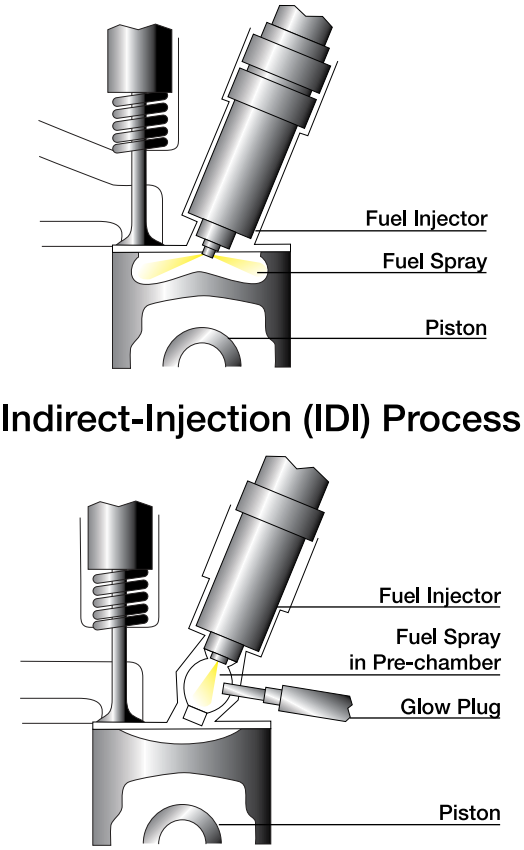
Fuel Injection Basics

Fuel injectors must produce a fine spray that will vaporize rapidly to ensure fast mixing of the fuel vapor and air. Placement of the injector in the cylinder head is carefully calculated to determine the best position and angle to enhance fuel vapor and air mixing. The design of the piston top and intake ports can help create a swirling motion of the air / fuel mixture in the cylinders.

Because the fuel is injected into an environment of hot compressed air, it must be injected late in the compression stroke, just before the piston reaches top dead center (TDC). This necessitates injection under very high pressures, as much as 2000 bar (29,000 psi).

There are two basic fuel injector designs, each with various subcategories. In a direct-injection (DI) system, the fuel is introduced directly into the cylinder. DI engines usually have compression ratios in the range of 15:1 to 18:1. Indirect-injection (IDI) injects the fuel into a small pre-chamber between the injector and the cylinder. IDI engines typically operate at higher compression ratios, in a range of 20:1 to 24:1. IDI systems create a more rapid mixing of the fuel and air. There are, however, some drawbacks. IDI systems lose more heat during compression. This is why IDI engines have higher compression ratios to reach the necessary air temperature. This usually results in fuel economy that is significantly lower than a DI engine. IDI engines may also be hard to start, which is why glow plugs are installed in the pre-chamber.

Figure 2-3



NOTE: The formula to convert bar to psi is *bar x 14.5038 = psi*

The primary interest in IDI systems is their ability to operate at higher engine speeds when there is less time to inject and mix the fuel per engine cycle.

Fuel Injection Systems

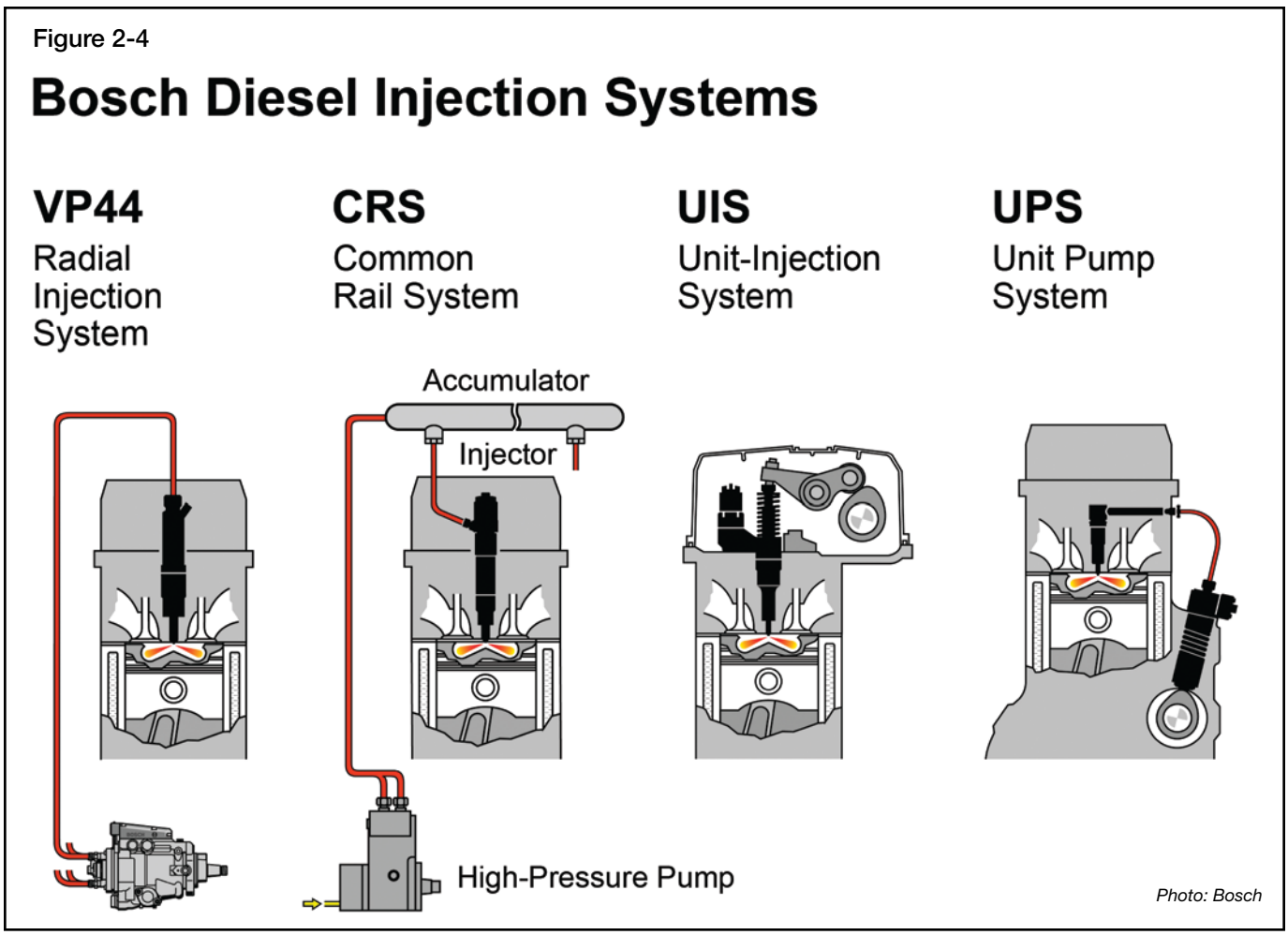
Among direct injection systems, there are several design options. These include the radial distributor injection system, the common rail system, the unit injector system and the unit-pump system. These systems are depicted in the following figures.

The distributor injection systems are typically found in passenger cars and light- to medium-duty trucks. Distributor injection systems for DI systems reach an injection nozzle pressure of up to 1,950 bar. These systems may be mechanically controlled or electronically controlled.

The common rail system's distinguishing feature is that the injection pressure is independent of engine speed and the volume of injected fuel. Pressure is generated by a high-pressure pump. The type of pump and control system varies between passenger vehicles and commercial vehicles. These systems operate at pressures of 1,600 bar or higher.

Earlier this decade, Bosch introduced the third generation of its common rail system for diesel engines. This high-pressure system operates at 1,600 bar and utilizes piezoelectric fuel injectors for precise fuel metering. Emissions are reduced by 15-

Figure 2-4



20 percent, while fuel economy is improved. Also, especially important for passenger vehicles, noise is reduced (see discussion on piezoelectric injectors later in this section).

Newer versions of this system operate at 1,800 bar. Denso Corporation has also introduced an 1,800 bar common rail injection system, using piezoelectric injectors for passenger cars. Delphi's Multec common rail injector system uses a patented technology called Accelerometer Pilot Control (APC). APC monitors combustion quality in the cylinder and provides input to the engine management system, allowing calibrations optimized to operating conditions. Although this system does not use piezoelectric injectors, Delphi is developing such injectors. These and other manufacturers also continue with their development programs, constantly trying to improve fuel management and combustion. Consequently, there are more types of diesel fuel injector systems available today than only a few years ago.

Unit-Injector systems can be found in both commercial vehicles and passenger cars. In commercial engines, the unit-injector is a complete module installed in the cylinder head. It has an integrated high-pressure pump and solenoid valve. As depicted in the preceding figure, this system is operated by a rocker arm, which is driven by an injection cam on the camshaft. Injection pressures on the unit-injector system can reach 2,000 bar. For passenger cars, the system is more compact and employs a mechanical-hydraulic pilot injection (double triggering of the solenoid valve) across the engine's operating range to reduce combustion chamber noise.

Figure 2-5

Bosch Common Rail System for Passenger Cars

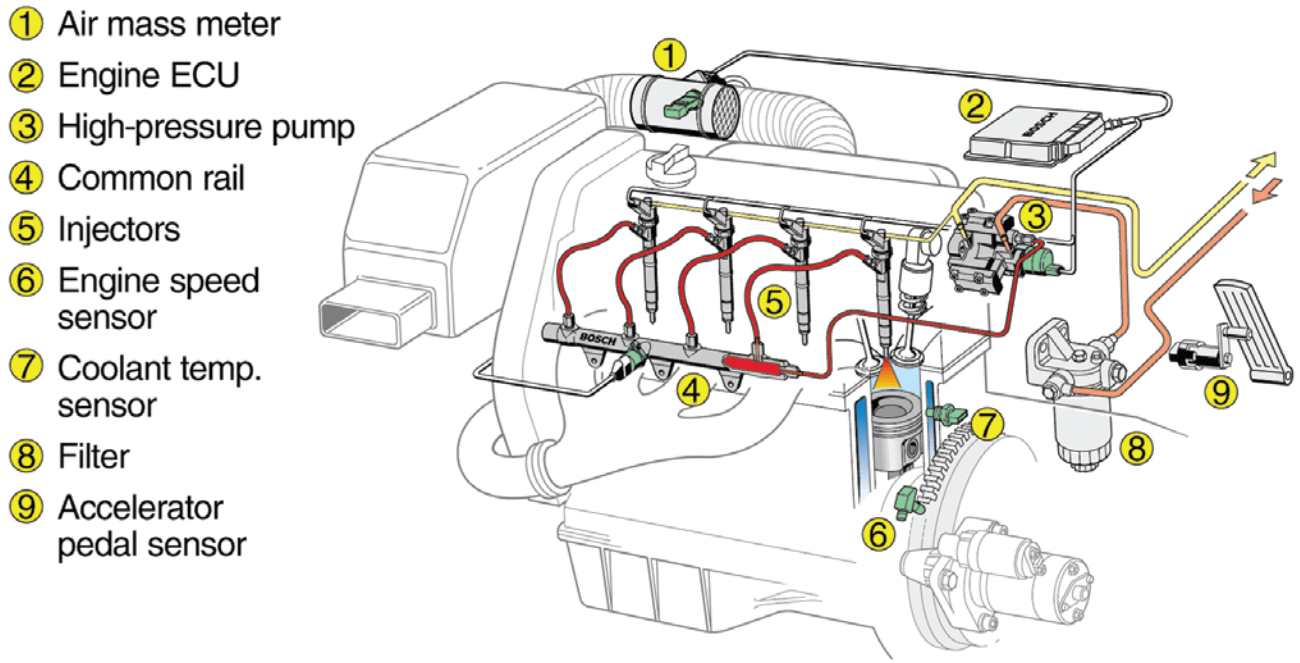


Photo: Bosch

The unit pump system is also found in both passenger cars and commercial vehicles. The unit pump system is similar to the unit-injector system. This system is also placed directly in the engine cylinder block, but is operated by roller tappets on the engine's camshaft. This system can also operate at 2,000 bar. The passenger car system is similar, but operated by rocker arms driven by an overhead valve (OHV) camshaft.

These are very basic descriptions of typical systems. Far more detailed descriptions are available

in other publications (See Appendix B – Additional Information Sources).

Fuel injection systems may employ conventional magnetic injectors or, increasingly, the piezoelectric injector. Piezoelectric injectors utilize a special ceramic material with a crystalline structure. The crystalline structure responds when voltage is applied and allows the unit to be controlled up to five times faster than a magnetic injector. This enables much more precise metering of the fuel, allowing multiple partial injections (up to six injections per cycle). These injections consist of pilot-injections, the main-injection and post-injection. The pilot-injection produces softer combustion, eliminating the "diesel knock" noise at cold start. Post-injection improves the combustion event, thereby reducing soot particles. As emission standards have become more stringent, there has been a major move to piezoelectric injectors.

With ever-more-precise metering systems, it is critical that diesel fuel properties are controlled and consistent.

Turbocharging: While a great deal of effort has been directed at emission controls, manufacturers are also spending a great deal of effort to improve fuel efficiency, increase power and reduce noise. One way to accomplish this is turbocharging. The latest innovation with turbocharging is the dual-stage turbo (sometimes called series turbocharging). Such systems use two turbochargers, each of which operates over specific portions of the engine range to optimize performance. These systems can increase specific output to 100 hp per liter of displacement and increase torque as much as 140 lb-ft. Obviously, packaging of the extra turbo can present challenges, and these systems add significant expense, which tends to limit their use to higher-priced vehicle categories. Use of these systems is also promoting development of alloy pistons to deal with the resulting higher peak cylinder pressures. Variable Geometry Turbochargers (VGT), which are currently more common, accomplish much the same affect as duel stage turbocharging.

EGR: Exhaust Gas Recirculation (EGR) is one of the most effective strategies for reducing NO_x emissions. The EGR system recirculates spent combustion gases into the intake system, which dilutes the oxygen concentration and increases the heat capacity of the air fuel charge. EGR coolers (after coolers) can be used to pre-cool the exhaust gases to reduce combustion temperatures, further reducing NO_x emissions. EGR may, however, increase engine wear. Other drawbacks are that EGR can negatively impact fuel economy and increase PM emissions. Work continues to find the optimum balance to decrease NO_x emissions without increasing PM emissions.

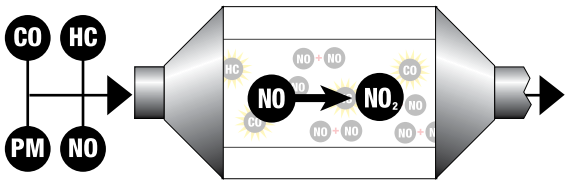
In addition, manufacturers are working on variants of EGR. For instance, in early 2006, Caterpillar announced it had developed a Clean Gas Induction System that draws clean inert gases from downstream of the particulate filter and injects them into the air intake. Since this gas is soot-free, it doesn't contribute to the engine wear that would result from the use of cooled EGR gases. The low intake manifold gas temperatures reduce NO_x and Caterpillar expects that the typical 3 percent fuel economy loss associated with cooled EGR will be eliminated.

After-Treatment Technologies: With the more stringent emission requirements that took effect for the 2007 model year, more is required than better control of fuel combustion, air intake and cooled EGR Systems. Engine-out emissions must undergo various forms of after-treatment. The following provides an overview of the more common after-treatment systems.

Diesel Oxidation Catalytic Converters are already in widespread use. In this system, the engine-out exhaust emissions of PM, NO, CO and HC enter the converter. The CO and HC are reacted with a catalyst that further reduces emissions while the NO is converted to NO_2.

Figure 2-6

Oxidation Catalytic Converter



In an oxidation catalytic converter, CO and HC are oxidized (combusted) while NO is converted to NO_2.

The oxidation catalytic converter is placed as close to the engine as possible in order to reach

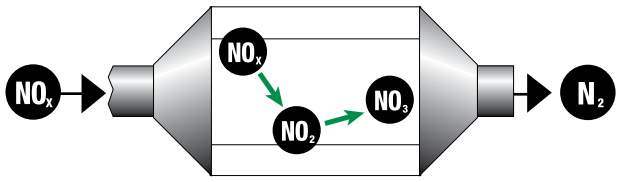
operating (light-off) temperature as quickly as possible. A sensor is placed post converter as a feedback device to the engine management system to determine that the system is functioning properly.

There are also NO_x Storage Catalytic Converters (SCC), commonly referred to as NO_x adsorbers or NO_x traps. These converters are placed downstream of the oxidation catalytic converter. The SCC has a special coating that traps NO_x from the exhaust gas. The unit has two different operating modes. In normal lean operations (Lamda >1), NO is oxidized to form NO_2 and via nitrate formation is stored in the converter on an alkaline metal oxide.

The second operations mode is the regeneration mode. This mode accomplishes the periodic purging of the NO_x accumulator. This necessitates rich exhaust gases (Lamda <1), which dissolve the nitrate bond and reduce it to nitrogen via a noble metal coated converter. This entire operating mode can occur in 30 to 60 seconds, with actual regeneration requiring only a few seconds. These systems require numerous temperature and pressure sensors to identify when regeneration is necessary. NO_x emissions can be reduced by as much as 85 percent.

Figure 2-7

Storage Catalytic Converter (NO_x Trap)



In a storage catalytic converter, NO_X is oxidized to NO_2 and then via nitrate formation to NO_3, which is stored in the converter. During the regeneration mode, the NO_3 nitrate bond is broken down to non-toxic nitrogen (N_2) and exhausted.

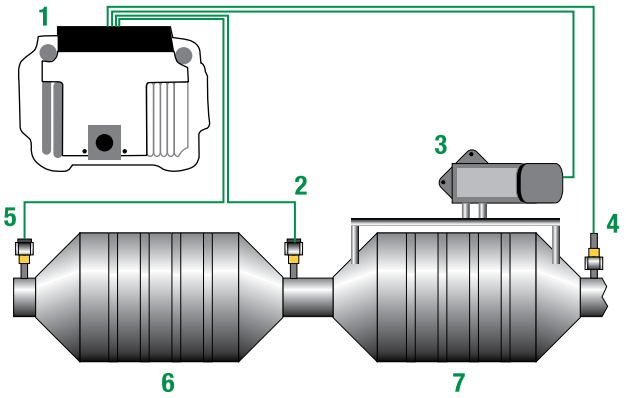
Another variant is the Selective Catalytic Reduction (SCR) System. This system uses a wash coated or extruded catalyst in conjunction with a chemical agent to convert NO_x to nitrogen and oxygen. These systems use what is called a reductant, typically a urea solution, which must be periodically replenished. SCR systems can reduce NO_x by 75 percent or more and HC emissions by up to 80 percent. PM emissions are typically reduced by 20 to 30 percent.

Similar SCR systems have been used in stationary sources such as power plants for years. However, it is only recently that they have started seeing use in diesel vehicles.

Diesel Particulate Filters (DPF) are designed to capture soot particles in the exhaust gas and then burn them. There are different systems with various levels of sophistication. The most up-to-date particulate filters can filter out nearly all particles of soot. These systems are commonly placed between the oxidation catalytic converter and the NO_x control catalyst. The diesel particulate filter is composed of honeycomb-like filters that force the exhaust gases through fine-pored intermediate walls, trapping the soot particles. These systems also require regeneration to prevent the particulate filter from becoming clogged, which would lead to increased back pressure. Regeneration requires high exhaust gas temperatures, in some cases as high as 550° C. Such temperatures would normally only occur under full load conditions. As a result, these systems require controls capable of increasing temperature via engine controls, injecting a small amount of fuel after the main combustion process or by special model calculations in the engine control module (ECM) to simulate a loaded condition. Some systems have been formulated that combine the DPF and NO_x trap in a single shell (can).

Figure 2-8

Diesel Particulate Filter



Design schematic of exhaust with particulate filter (1) ECU, (2) Temperature sensor, (3) Differential-pressure sensor, (4) Soot sensor, (5) Temperature sensor, (6) Oxidation catalytic converter, (7) Particulate filter.

As discussed later in this section, it is the development of these more sophisticated emission control systems that has led to the need for very low sulfur levels in diesel fuels.

Engine Oil and Coolant

Although this manual's focus is on diesel fuels, it is important to mention that a new engine oil designation has been developed for 2007 model year engines and exhaust after-treatment systems. In February 2006, the American Petroleum Institute's (API) Engine Oil Committee issued requirements for the newly designated engine oil category API CJ-4. API CJ-4 engine oil meets the highest standards developed to date, and it will have lower ash levels to meet 2007 requirements and to ensure that diesel particulate filters can achieve the EPA's requirement of 150,000 miles between service intervals.

Fleet operators will need to decide what engine oils they wish to keep in inventory. One option is to stock an API CJ-4 for 2007 model year vehicles (or newer) and continue to stock the CI-4 Plus engine oil for older models. Another option is to simply use API CJ-4 in all vehicles. Due to the increased operating temperatures and correspondingly high temperature of engine oil and coolant, and in some cases a higher level of EGR gases, oil change intervals are more important than ever. Some fleet operators are even reviewing and updating their engine oil analysis programs. Also, because of resultant higher engine oil temperatures, some fleet operators are reevaluating the use of premium extended-life coolants which can reduce coolant temperatures.

Retrofit Technologies

One thing somewhat unique with diesel engines/vehicles is the ability to retrofit older systems with newer technology. Diesel engines/vehicles have useful lives many times that of spark-ignition engines. New technologies would normally not have an immediate impact, since the fleet takes a long time to turn over. But a number of retrofit technologies are available for older diesel engines/vehicles. The EPA has a voluntary retrofit program. Several municipal fleets have adopted, or are considering adopting, retrofit strategies.

There are a number of retrofittable technologies. High Efficiency Diesel Particulate Filters are available, along with the low-pressure EGR systems to use in conjunction with them. Diesel Oxidation Catalysts can also be retrofitted, as can Selective Catalytic Reduction and NO_x Adsorbers.

Retrofit equipment must, however, be approved by the U.S. EPA.

Compliance Strategies – Diesel Fuel

Sulfur is a natural component of crude oil and products refined from it. Sulfur dioxide (SO_2) is produced when fuels containing sulfur are combusted. Sulfur dioxide is a major precursor to acid rain. It is also a lung irritant. Furthermore, it can reduce the effectiveness of exhaust after-treatment devices. In 1993, regulations from the EPA and the CARB went into effect. The EPA set a maximum of 500 ppm for on-road diesel fuel, while the CARB required the same level for both on-road and off-road diesel fuels. This fuel was referred to as low-sulfur diesel. The CARB also limited the maximum aromatic content to 10 volume percent, but provided an alternative compliance mechanism which allows refiners to formulate fuels that, though higher in aromatics, would meet the same or lower emissions of a fuel containing 10 volume percent aromatics. However, for the newest technology exhaust after-treatment devices to operate effectively, sulfur must be kept to much lower levels.

In mid-2006, the EPA required that the majority of diesel fuel produced or imported for on-road use contain no more than 15 ppm sulfur, and this fuel is referred to as Ultra-Low Sulfur Diesel (ULSD). All on-road diesel and most off-road diesel will be required to meet a 15 ppm standard beginning in 2010, with locomotive and marine fuels produced by most refiners required to meet the standard in 2012.

Owners of 2007 model year or newer vehicles must use ULSD, because fuels with higher sulfur levels than ULSD can render their advanced exhaust after-treatment devices ineffective. Model year 2006 and earlier models of on-road vehicles may be fueled with low sulfur diesel where it is still available. Currently 80 percent of on-road diesel fuel must be ULSD. By December 1, 2010 all on-road diesel must be ULSD. The sulfur content

of diesel may be identified by decals on the fuel dispenser (see below).

The hydro-treating process that is used to reduce sulfur levels in diesel will also reduce the level of naturally occurring components that provide lubrication properties to diesel fuel. Diesel fuel manufacturers will add the necessary additives to ensure that ULSD meets the lubrication requirements of ASTM D 975. The hydro-treating process can also reduce the energy content of the fuel by 1 to 2 percent. Under normal operating conditions, this small change should not affect overall power, but may reduce fuel economy slightly.

Renewable Fuels Standard

In addition to environmental regulations, there are also energy regulations that are causing changes in diesel fuel composition. The 2005 Energy Policy Act requires that an ever-increasing amount of the Nation's transportation fuel supply come from renewable sources, such as ethanol and biodiesel. The use of biodiesel is increasing so rapidly that the next chapter is dedicated entirely to that subject.

Figure 2-9

Diesel Dispenser Labeling Requirements

ULTRA-LOW SULFUR HIGHWAY DIESEL FUEL
(15 ppm Sulfur Maximum)

Required for use in all model year 2007 and later highway diesel vehicles and engines.

Recommended for use in all diesel vehicles and engines.

LOW SULFUR HIGHWAY DIESEL FUEL
(500 ppm Sulfur Maximum)

WARNING
Federal Law ***prohibits*** use in model year 2007 and later highway vehicles and engines.

Its use may damage these vehicles and engines.

NON-HIGHWAY DIESEL FUEL
(May Exceed 500 ppm Sulfur)

WARNING
Federal Law ***prohibits*** use in highway vehicles or engines.

Its use may damage these vehicles and engines.

Normally, the diesel fuel sold at the primary vehicle island is ULSD. Low sulfur diesel grades with up to 500 ppm sulfur may be available at some locations through December 2010. It is illegal to use anything other than ULSD in the case of 2007 model year and newer vehicles because using higher sulfur level fuels will render exhaust after-treatment devices ineffective or, at minimum, less effective.

B20 Chapter 3: Biodiesel and Biodiesel Blends

The Energy Policy Act of 2005 requires an ever-increasing amount of the Nation's transportation fuel supply to be from renewable sources. While this legislation does not require the use of a specific renewable fuel, at present the focus has been on ethanol (for use in spark-ignition engines) and biodiesel. In 2006, actual production of biodiesel reached only 225 million gallons. By mid-2007, U.S. production capacity of biodiesel reached 1.3 billion gallons, with another 1.8 billion gallons of capacity under construction. This will bring nameplate production capacity of biodiesel to over 3 billion gallons per year in the near future.

Biodiesel and Biodiesel Blends

Biodiesel can be made from a variety of sources including the oil from oil seeds such as soybeans, palm kernel and canola, to name only a few. It can also be made from animal fat-based feedstocks such as beef tallow and recycled cooking oils (e.g., French fryer oil). In the United States most plants are set up to run soybean oil as the feedstock, although some plants can run multiple feedstocks, including corn oil. The selection of soybean oil for U.S. plants is simply a reflection of the abundant U.S. supply of soybeans. In other countries, such as India and Malaysia, other feedstocks such as palm oil are used due to their greater availability in those nations.

Regardless of the feedstock used, the process to produce biodiesel is essentially the same. From a chemical standpoint, vegetable oils are triglycerides of fatty acids and possess properties that are not desirable in diesel fuel. For instance, they may cause injector coking. While diesel engines running on French fryer oil may make for a great media story, it does not make for great diesel fuel quality. Almost all engine manufacturers recommend against the use of raw pressed, or partially refined, vegetable oils that have not been processed through transesterification.

In order to overcome the unfavorable properties of vegetable oils and animal fats, they are reacted with an alcohol (usually methanol, but ethanol or other alcohols could be used). The triglycerides are combined with methanol and reacted with a catalyst to yield biodiesel and glycerin. Essentially this reaction uses the alcohol to remove the glycerin, which is undesirable in diesel fuel. This process is called transesterification, and the resulting biodiesel is technically a Fatty Acid Methyl Ester (FAME) when methanol is the alcohol used. The resulting biodiesel has chemical and physical properties similar to conventional diesel fuel.

Although biodiesel can be, and is in some cases, used as a fuel by itself, it is more commonly used as a blend component in conventional diesel. Biodiesel levels typically range from 2 volume percent (B2) to 20 volume percent (B20) of the total biodiesel blend, with the remainder of the blend being conventional diesel.

While biodiesel production and use are increasing significantly in the U.S. it has been widely available only over the past few years. Engine and fuel system manufacturers have been engaged in various research projects to determine which biodiesel blend levels are appropriate for their products. In addition, as biodiesel blend sales have increased, manufacturers are rapidly gaining field experience to aid in such decisions.

ASTM Specifications

As is the case for diesel fuels, ASTM International has a specification for biodiesel. That specification is ASTM D 6751- Standard Specification for Biodiesel Fuel Blendstock (B100) for Middle Distillate Fuels. This specification applies to biodiesel for use as a blend component in diesel. ASTM has not yet developed a specification for blends such as B5 and B20, but expects to do so in the future.

ASTM D 6751 includes limits on several of the same properties that ASTM D 975 requires for No. 2 diesel fuel. However, there are additional property requirements for biodiesel.

Additional requirements for biodiesel include a maximum limit of 5 ppm for calcium and magnesium (combined). Calcium and magnesium may be present as abrasive solids or soluble metallic soaps, so their presence must be limited, because abrasive solids would contribute to injector and pump wear as well as piston and ring wear. Soluble metallic soaps contribute to engine deposits. Calcium and magnesium may also collect in particulate filters, increasing back pressure, and may result in the need for shorter service intervals.

Alcohol content is limited in one of two manners. Either the alcohol content must not exceed 0.2 mass percent, or the flash point must be 130°C minimum. This is done to ensure that the alcohol used in the transesterification process is properly removed from the fuel.

While ASTM D 975 has a limit on ash, ASTM D 6751 specifies a "sulfated ash" maximum of 0.02 mass percent. In addition to limiting abrasive solids and soluble soaps (see above), this specification

Table 3-1

ASTM Requirements for Biodiesel (B100)

Property	Units	Grade S15 Limits	Importance
Calcium and magnesium, combined	ppm (µg/g)	5 max	To protect against wear of injectors, pumps, pistons & ring and also engine deposits & premature failure of particulate filters
Flash point	°C	93 min	Safety during fuel handling & storage
Alcohol control - One of following must be met: 1. Methanol content 2. Flash point	 % mass °C	 0.2 max 130 min	To ensure alcohol from manufacturing process is properly removed
Water and sediment	% volume	0.050 max	Filter plugging, injector wear, increased corrosion
Kinematic viscosity, 40°C	mm2/s	1.9-6.0	Injector wear & spray pattern, pump wear, filter damage
Sulfated ash	% mass	0.020 max	Limits unremoved catalyst from fuel to protect against wear in injector pumps, pistons, rings & reduce engine deposit
Sulfur	% mass (ppm)	0.0015 max (15)	To protect emissions control equipment
Copper strip corrosion		No. 3 max	Protect copper, brass, bronze fuel system parts
Cetane number		47 min	Measure of ignitability (ignition quality)
Cloud point	°C	ReportD	Low-temperature operability
Carbon residue	% mass	0.050 max	To reduce deposits in fuel system and engine
Acid number	mg KOH/g	0.50 max	Protect against fuel system deposits & corrosion
Free glycerin	% mass	0.020	Injector deposits & fuel system clogging
Total glycerin	% mass	0.240	Injector deposits, filter plugging & low-temperature operability
Phosphorus content	% mass	0.001 max	Protect catalysts in exhaust after-treatment devices
Distillation temperature, 90% recovered	°C	360 max	Affects fuel economy and power under varying loads/speeds
Sodium and potassium, combined	ppm (µg/g)	5 max	Limits unremoved catalyst from fuel to protect against wear in injector pumps, pistons, rings & reduce engine deposit
Oxidation stability	hours	3 min	Storage stability, prevent degradation of fuel

Note that the above specifications are identical for biodiesel blended into ULSD (grade S15) and low-sulfur diesel (grade S500), except that grade S500 is permitted to have up to 500 ppm sulfur while grade S15 is limited to 15 ppm sulfur.

limits any unremoved catalysts from the biodiesel production process. Carbon residue is limited to 0.05 mass percent, but a different test method is used than that for No. 2 diesel fuels. An acid number specification limit of 0.50 maximum mg KOH/g is placed on biodiesel to control the level of free fatty acids or processing acids. High acidity can increase fuel system deposits. It may also increase fuel system corrosion. High acid values may also be an indication of fuel degradation from oxidation. Free glycerin is limited to 0.02 mass percent and total glycerin is limited to 0.24 mass percent. High levels of free glycerin can contribute to injector deposits and clogging of the fuel system. Free glycerin can also build up in the bottom of storage tanks. The total glycerin includes free glycerin plus any glycerin content of any unreacted or incompletely reacted oils or fats. Low levels of total glycerin confirm a high conversion rate of oils and fats. High levels of total glycerin can contribute to injector deposits and fuel filter plugging and could impact low-temperature operability.

A limit is placed on phosphorus, because it can damage exhaust after-treatment catalysts. The ASTM maximum limit for phosphorus in biodiesel is 0.001 mass percent (10 ppm). U.S. biodiesel (soybean oil based) has routinely been in the 1 to 2 ppm range, but biodiesel from other feedstock sources could contain higher phosphorus levels.

Sodium and potassium may be present as abrasive solids or soluble metallic soaps, resulting in problems similar to those described for sulfated ash. Finally, an oxidation stability rating or 3 hours minimum under specified test conditions is required. This test provides an indication of the storage life of biodiesel, which is known to degrade more quickly than standard diesel fuel. The remainder of the requirements are similar to those for standard diesel fuel. Table 3-1 lists the ASTM D 6751 requirements for biodiesel and a brief recap of why they are necessary.

The previous table lists property limits for B100, and the text preceding it discusses property limits unique to the biodiesel specification. It also includes property limits similar to the No. 2 diesel specification for certain categories.

Table 3-2

Comparison of Selected ASTM Specifications of No. 2 Diesel and Biodiesel

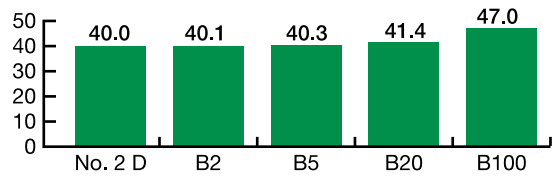
Property	No. 2 D	B100
Flash point °C min	52	93
Water and sediment, % vol	0.05	0.05
Kinematic viscosity mm2/s at 40°C		
min	1.9	1.9
max	4.1	6.0
Sulfur ppm (µg/g max)	15	15
Copper strip corrosion	No. 3 max	No. 3 max
Cetane number minimum	40	47
Cloud point	-	-
Carbon residue maximum % mass	0.15	0.05

Table 3-2 lists a comparison of ASTM specified properties for No. 2 Diesel and B100. The Flash Point for B100 is a minimum 93°C compared to 52°C for No. 2 diesel. This still allows biodiesel to fall under the nonhazardous category under National Fire Protection Association codes.

The only other major differences between the two fuels in the above table are viscosity and cetane. In the case of viscosity, it is desirable to express a range. Minimum viscosity is specified because of potential loss of power due to injector pump leakage and injector leakage. Maximum viscosity is limited because of practical considerations of the engine size and design, as well as the operating parameters of the injection system. The upper limit of viscosity for biodiesel is higher than for No. 2 diesel. Blending biodiesel which has a viscosity rating near the maximum limit could cause the biodiesel blend to exceed the maximum viscosity limit specified for No. 2 diesel, especially for higher concentration biodiesel blends.

The cetane number requirement for biodiesel is 47 compared to 40 for No. 2 diesel. The impact this has on the blend depends on the blend level. For B2, the cetane number only increases to 40.1, and for B5 to a still-modest 40.3. For B20, the cetane number increases to 41.4 (see Figure 3-1 on the next page).

Figure 3-1

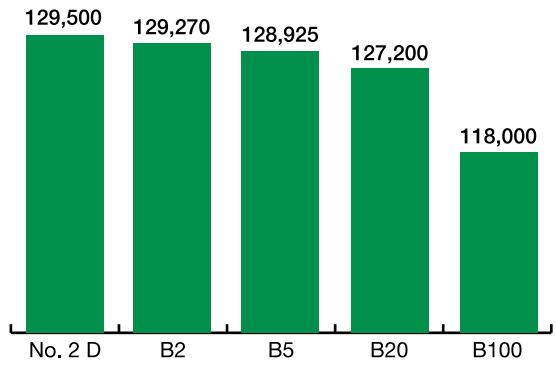


Other Properties of Interest

There are other properties of interest which are not specified in the ASTM Specification. These include the following:

Energy Content: No. 2 diesel has a btu content of approximately 130,000 btu/gal. Biodiesel's energy content is approximately 118,000 btu/gal. The impact this has on the biodiesel blend depends on the blend level. The following figure depicts the energy content of different blend levels using 129,500 btu/gal. for No. 2 diesel and 118,000 btu/gal. for B100.

Figure 3-2



As the graph shows, the decrease in energy content for B2 is less than 0.2 percent, and for B5 still below 0.5 percent. For B20 blends, the energy content is 1.8 percent lower. Such modest changes should not result in noticeable power loss or significant changes in fuel economy. On the other hand, B100 has about 8.9 percent lower energy content, which may result in lower power and noticeably lower fuel economy.

Lubricity: There is not currently a lubricity specification in ASTM D 6751. However, biodiesel is known to improve the lubricity of No. 2 diesel. In fact, biodiesel is often added at the 2 volume percent level to improve the lubricity of No. 2 diesel, making B2 probably the most common biodiesel blend. The lubricity of No. 2 diesel is limited to 520 microns of wear in the HFRR test, while B100 typically achieves levels of below 300 microns.

Cloud Point/Pour Point: As noted earlier, there are no limits set for cloud point or pour point for No. 2 diesel. It is known that B100 has a cloud point about 7ºC higher than No. 2 diesel and a pour point of 20ºC to 25ºC above No. 2 diesel. In other words, the low-temperature operability of B100 is poorer than that of No. 2 diesel. This is usually not noticeable at the B2 and B5 blend levels. However, at higher levels, biodiesel blenders may need to use additives to improve low-temperature operability.

It is important to again note that information presented here is based largely on soy methyl ester (SME). However, biodiesel (FAME) can be made from a variety of feedstocks, and the different feedstocks may result in biodiesel with slightly different properties. For instance, SME can tolerate lower temperatures than animal-based biodiesel before reaching its cold filter plug point. Similarly, the cetane number can vary. This is largely a function of the carbon content of the final FAME, which can vary with feedstock type. However, for the B2 to B20 blend levels, these differences are rarely perceptible. ASTM D 6751 is intended to apply to all biodiesel produced from any feedstock.

Other Fuel Quality Considerations

Biodiesel (B100) possesses certain properties that make it more sensitive to storage conditions than No. 2 diesel. This makes proper storage, transport and blending of biodiesel very important. Biodiesel is hygroscopic, meaning it absorbs water. Over a period of time the water content of biodiesel can rise to its saturation point (around 1200 ppm). This can increase the risk of corrosion as well as microbial contamination. Fuel storage systems must be kept free of water. Additional steps could include treatment with moisture dispersants and biocides. Biodiesel has a greater solvency effect

than No. 2 diesel. It will remove sediment and residual contaminants in storage tanks. Storage tank cleaning and preparation are very important. Biodiesel may deteriorate more quickly than No. 2 diesel. This necessitates steps such as monitoring product turnover as well as painting above-ground storage tanks a reflective color to reduce product temperature during storage.

While the above steps are not part of the ASTM specifications, they are part of the BQ-9000 Accreditation Program. This program is a cooperative and voluntary accreditation program for biodiesel producers as well as marketers of biodiesel and biodiesel blends. The National Biodiesel Accreditation Program (NBAP) oversees the BQ-9000 program. Commissioners to the NBAP board are approved by the Board of Directors of the National Biodiesel Board (NBB). The NBAP Commissioners represent a wide scope of stakeholders (interested parties) who have full authority to operate the BQ-9000 program.

BQ-9000 accredited producers adhere to the standards set forth in ASTM D 6751 and ensure the company is using proper sampling, testing, storage and shipping procedures. BQ-9000 Certified Marketers agree to procedures that ensure the proper storage, blending and handling of biodiesel and biodiesel blends. This is important because, as previously noted, proper procedures in this area are important for delivering on-specification product.

The BQ-9000 program also includes accreditation audits, surveillance audits and periodic recertification audits. In summary, the BQ-9000 program combines accepted quality management systems with the ASTM D 6751 specification, and also covers storage, handling, testing, shipping, etc. BQ-9000 producers can prove that any batch of the B100 they have produced meets the ASTM specifications.

Some diesel engine and vehicle manufacturers recommend that biodiesel and biodiesel blends be purchased from a BQ-9000 accredited producer or BQ-9000 certified marketer (see Appendix A).

The Benefits and Concerns of Biodiesel and Biodiesel Blend Use

The driving force for biodiesel production and use is primarily public policy benefits. The use of biodiesel reduces U.S. dependence on foreign crude oil, lowers greenhouse gas emissions and lowers PM emissions. Biodiesel production also contributes to the rural economy. However, public policy benefits are not the focus of this manual.

The performance and operability benefits of biodiesel include reduced net CO_2 emissions, reduced HC and CO emissions and lower visible smoke. Biodiesel also has a higher cetane number and contains no aromatics. It has a low sulfur content and improves lubricity. Biodiesel is also nontoxic and biodegradable.

The performance and operability concerns most often expressed by the diesel engine and vehicle manufacturers include several topics. First, there are concerns about materials compatibility. Biodiesel may cause corrosion of certain metals. These include zinc, copper-based alloys, tin, lead and zinc. Certain elastomers and seal materials may also harden or swell. These effects may be more pronounced on older vehicles or equipment and may increase with biodiesel concentration in the blend.

There is also concern with the potential for increased water contamination, which could increase corrosion as well as the potential for microbial contamination. Biodiesel may also increase NO_x emissions, especially at higher blend levels. The catalyst can typically handle small increases in engine-out NO_x emissions. This is of particular concern with engines certified to the more stringent 2007 NO_x emission standards, because it could have implications for the emission certification equipment, the life of which must be warrantied for very lengthy periods.

Biodiesel may negatively impact low-temperature operability unless additized. Additization may also be necessary to address manufacturers' concerns that the thermal and oxidative stability of biodiesel is poorer than No. 2 diesel. At higher blend levels, and especially at the B100 level, power output and fuel economy are reduced. Manufacturers have also expressed concern about potential damage to paint due to biodiesel's solvency effect. This solvency effect can also loosen sediments and contaminants in the fuel tank and plug fuel filters upon initial use of biodiesel.

Concerns about the special handling of biodiesel have also been mentioned, because it is difficult to confirm that all proper handling guidelines have been followed.

Lastly, although not a performance issue, it should be mentioned that biodiesel costs more to produce than petroleum-based diesel fuel. At present, biodiesel tax credits help keep biodiesel reasonably competitive with petroleum-based diesel.

Table 3-3

Benefits and Concerns – Biodiesel and Biodiesel Blends	
Benefits:	1. Higher cetane 2. Improved lubricity 3. Low sulfur content 4. Reduces HC and CO emissions 5. Reduces PM emissions 6. Lowers visible smoke 7. Zero aromatics 8. Reduces net CO_2 emissions on life-cycle basis 9. Nontoxic and biodegradable
Concerns:	1. Materials compatibility – especially with higher blend levels 2. Potential for increased water content and microbial contamination 3. Increase in NO_x emissions 4. Implications for emission control equipment 5. Impact on low-temperature operability if not properly additized 6. Reduced power and fuel economy (on B100) – lower energy content 7. Thermal and oxidative stability poorer than No. 2 diesel 8. Solvency effect may plug filters on initial use 9. Requires special care and handling 10. Spills could damage paint 11. Higher cost

Manufacturer Guidelines

For the service technician, it is important to know what diesel engine and equipment manufacturers recommend as approved biodiesel blend levels, as well as any increased service requirements or special maintenance needs. Most manufacturers have expressed their support for increasing the production and use of biodiesel. However, it is important to recognize that it is only recently that biodiesel blends have been more widely marketed in the U.S. Manufacturers have only a limited amount of field experience, complemented by research and testing programs, upon which to base their recommendations for biodiesel use. As such, the guidelines currently vary from one manufacturer to another. Most manufacturers permit the use of B2 and B5. Some permit the use of B20 or permit its use under special circumstances. Only a few manufacturers permit the use of B100.

Manufacturer approval of biodiesel blend use may cover an entire product line, but more often applies only to specific vehicles, model years or engine families.

The fuel injection equipment (FIE) manufacturers have thus far limited their use recommendations to the B5 level.

Regardless of the permitted blend level, nearly every manufacturer stipulates certain use requirements and usually increased maintenance or service intervals.

Most manufacturers require that the biodiesel used in the blend meet the specifications set forth in ASTM D 6751 (in some cases meeting the European Standard EN 14214 may also be required). Several also specify, or recommend, that the biodiesel or biodiesel blend be supplied by a BQ-9000 accredited producer or BQ-9000 certified marketer. Most also note that, similar to their position on diesel fuel and gasoline, warranty claims resulting from the use of off-specification or low-quality fuel may not be honored.

Several manufacturers recommend more frequent fuel filter changes, with some specifying certain filter media. In the case of farm tankage or storage tanks for fleet operations, some manufacturers recommend adding a biocide to the fuel, adding an in-line filter to the storage tank dispensing system, and adding a fuel/water separator. Some manufacturers also recommend keeping storage tanks as full as possible to reduce the potential for condensation of water on storage tank walls. Many also recommend adding an antioxidant to stored product to improve its shelf life or recommend that

biodiesel not be stored for more than three months before it is used.

Certain manufacturers have expressed concern that uncombusted biodiesel (especially at higher blend levels) may get past piston rings and dilute engine oil. Such manufacturers recommend checking engine oil levels daily to see if the oil level increases (an indication of potential engine oil dilution). They may also recommend increased oil change intervals due to such concerns. However, there is considerable technical data indicating engine oil dilution should not be a problem for conventional fuel systems.

Other manufacturer recommendations include using lower blend levels, such as B2 or B5, during cold weather due to concerns about cold flow properties. An alternative recommendation offered by some is to add a cold flow improver additive to address low- temperature operability concerns. Additional recommendations may include warnings about spilling biodiesel on painted surfaces, because it could cause paint damage. A number of manufacturers also provide recommendations about storing vehicles or equipment. Several recommend that their products not be stored for extended periods with biodiesel in them.

Finally, several manufacturers note that their biodiesel research and testing programs, especially at higher blend levels, are ongoing. They note that as they gain more field experience and complete additional testing, recommendations may be revised.

While this section presents an overview, Appendix A provides excerpts from owner's manuals, service bulletins and other sources stating several major diesel engine and vehicle manufacturers' positions and recommendations on biodiesel. As noted above, these positions and recommendations could change, so the specific owner's manual or manufacturer's Web site should be reviewed.

Retail Dispenser Labeling

Requirements to label biodiesel content on the retail fuel dispenser vary among states. Some may not have adopted any biodiesel labeling laws yet. Others often require labeling only for blends containing more than 5 volume percent biodiesel. Several states have adopted the biodiesel labeling requirements from NIST Handbook 130, or have used the requirements as a model to develop labeling regulations.

The wording contained in NIST Handbook 130 was developed by the NCWM Petroleum Subcommittee with input from all interested parties. The Engine Fuels, Petroleum Products, and Automotive Lubricants Regulation in NIST Handbook 130 states in part:

Biodiesel.

Identification of Product. – Biodiesel and biodiesel blends shall be identified by the capital letter B followed by the numerical value representing the volume percentage of biodiesel fuel. (Examples: B10, B20, B100)

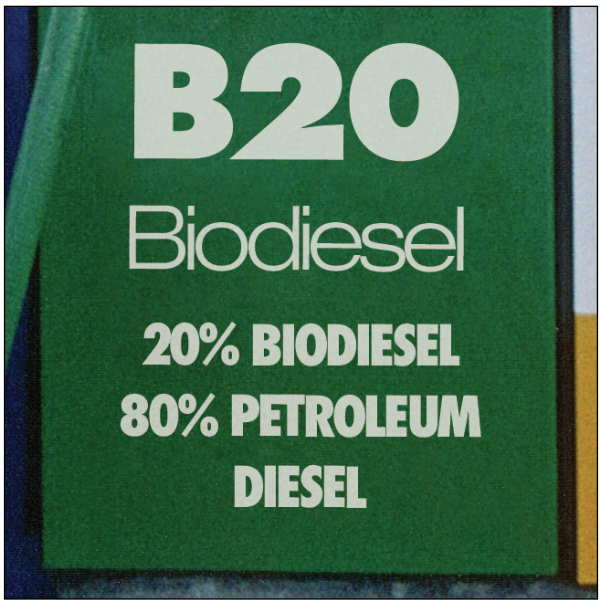
Labeling of Retail Dispensers Containing Between 5% and 20% Biodiesel. – Each retail dispenser of biodiesel blend containing more than 5% and up to and including 20% biodiesel shall be labeled with either:

The capital letter B followed by the numerical value representing the volume percentage of biodiesel fuel and ending with "biodiesel blend". (Examples: B10 biodiesel blend; B20 biodiesel blend), or

The phrase "biodiesel blend between 5% and 20%" or similar words.

Figure 3-3

B20 Dispenser Labeling



Labeling of Retail Dispensers Containing More Than 20% Biodiesel. – Each retail dispenser of biodiesel or biodiesel blend containing more than 20% biodiesel shall be labeled with the capital letter B followed by the numerical value representing the volume percentage of biodiesel fuel and ending with either "biodiesel" or "biodiesel blend". (Examples: B100 biodiesel; B60 biodiesel blend)

Exemption. – Biodiesel blends containing 5% or less biodiesel by volume are exempted from the requirements of Section 3.15.

The above requirements exempt blends of B5 or lower. However, most retail outlets label biodiesel blends voluntarily. Most marketers view renewable fuels as a marketing advantage, because it is a product many consumers prefer. Consumers should check retail dispenser labels to determine the biodiesel content of the blend being dispensed.

Other Diesel Fuel Alternatives

While biodiesel is the most widely used form of renewable diesel fuel used, other alternatives are being pursued. Some alternatives are based on renewable feedstocks, while others are not. For instance, work is ongoing with gas-to-liquid (GTL) fuels. This process can convert gases to a very clean, high cetane product with properties very similar to diesel fuel. This alternative fuel is, however, still fossil fuel-based. Other processes are being explored, such as biomass-to-liquids (BTL), which could convert various forms of biomass to diesel-like fuels. This product is referred to as renewable diesel, but it is not biodiesel, which more commonly refers to transesterified vegetable oils or animal fats. Obviously, biodiesel is also a renewable diesel, but the term 'biodiesel" is the common terminology.

Some may occasionally see the term "E-diesel." E-diesel is a blend of No. 2 diesel fuel containing up to 15 volume percent ethanol and certain proprietary additives, although ethanol is more commonly blended at the 7.7 volume percent blend in E-diesel. This is not presently a commercially available fuel, but it is being used in some demonstration fleets. Diesel engine and vehicle manufacturers have expressed strong reservations about diesel fuels containing ethanol. A great deal more research will be required on this product. As such, when, or if, E-diesel would be introduced as a commercially available fuel is uncertain.

Frequently Asked Questions

This section lists some of the more common frequently asked questions (FAQs) that the diesel service technician encounters, along with appropriate answers. This section is meant to provide a quick reference guide for dealing with consumers, diesel operators and others who may be seeking advice or recommendations on diesel fuel use.

Q: Should I use ULSD in my 2007 or newer model year diesel vehicle?

A: Yes, ULSD is required to protect emissions control equipment.

Q: Can I continue to use low sulfur diesel (instead of ULSD) in my pre-2007 model year diesel vehicle?

A: Some low sulfur diesel may be available until December 2010. Until that time you may use it in your pre-2007 vehicles. Beginning December 2010 ULSD will be the only legal on-road diesel fuel.

Q: What cetane level diesel fuel should I purchase?

A: Cetane number is not always posted on the retail dispenser. However, the minimum ASTM requirement of 40 should provide adequate cetane quality for nearly all engines and operating conditions.

Q: What over-the-counter additives should I add to my diesel fuel?

A: Refiners add any necessary additives based on extensive fuel test results. It is not necessary to add over-the-counter additives. In the case of biodiesel blends, certain additives such as biocides or antioxidants may be recommended, but this normally applies to product in the retail storage tank – not the vehicle tank.

Q: Should I use premium diesel fuel?

A: The definition of premium diesel fuel varies in different areas of the country. If the premium diesel meets the requirements of NIST Handbook 130 (see page 10), you may experience improved operations, especially during cold weather.

Q: Do I need any special engine oil for my 2007 or newer model year diesel vehicle?

A: Yes, 2007 and newer model year vehicles require engine oil meeting API's engine oil category API CJ-4.

Q: Will the use of ULSD affect power or fuel economy?

A: There should be no noticeable decrease in overall power under normal operating conditions. Fuel economy may be reduced slightly (1 percent - 2 percent) because the process used to remove sulfur from the fuel can reduce the fuel's energy content.

Q: Will ULSD have similar low-temperature operability to low sulfur diesel?

A: With only one winter season of use, it is difficult to answer definitively. Based on testing, it was thought that the low-temperature operability of ULSD would be similar to low sulfur diesel. However, at least one major truck stop operator did report low-temperature operability problems in the 2006/2007 winter period. As more experience is gained, it may be necessary to modify low-temperature operability additive treat rates.

Q: What is Biodiesel?

A: Biodiesel can be made from the oil in oil seed crops and also from animal fats. It then undergoes a process called transesterification, which removes glycerin from the fuel. The result is a product very similar to diesel fuel.

Q: Can I simply operate my vehicle on raw vegetable oil?

A: No, raw pressed oils contain undesirable components and can, among other things, increase fuel system and engine deposits. Most manufacturers recommend that you not use vegetable oils or animal fats that have not been transesterified (i.e., converted to biodiesel).

Q: Can I use biodiesel or biodiesel blends in my diesel engine?

A: Approval for using biodiesel varies among diesel engine and equipment manufacturers. Most approve of the use of B2 and B5. Some permit the use of B20 in certain engines. Most do not currently approve the use of B100. The owner's manual or engine/vehicle manufacturer Web site should be consulted to confirm the level of biodiesel that is approved for use.

Q: If I use a biodiesel blend, do I need to make any engine or fuel system adjustments?

A: Blends up to B20 can be used with little or no modifications. Some manufacturers do recommend certain modifications for higher-level biodiesel blends, especially those above B20.

Q: Are there any special handling considerations for biodiesel?

A: Yes. Biodiesel can pick up moisture, so it is very important to take steps to eliminate any potential for water getting into storage tanks as well as vehicle tanks.

Q: Will biodiesel cause fuel filter plugging?

A: Biodiesel has a solvency effect and will remove sediment and gums built up in the fuel system. These materials become trapped in the fuel filter, which may require a change. This is normally a one-time occurrence upon initial biodiesel use. Once the system is clean, fuel filter change intervals should be similar to that for No. 2 diesel.

Q: Will my vehicle perform satisfactorily on biodiesel blends?

A: A blanket answer is difficult for all vehicles and all blend levels. In general, most drivers have found performance to be satisfactory on blends up to B20.

Q: If I use biodiesel, will my fuel economy be affected?

A: Depending on the blend level, it may be. The energy content of a B2 blend is only 0.2 percent lower than No. 2 diesel, and a B5 blend is 0.5 percent lower. The energy content of B20 is 1.8 percent lower.

Q: What is BQ-9000 Biodiesel?

A: BQ-9000 is an accreditation program for biodiesel producers and marketers. Biodiesel producers that are BQ-9000 accredited, and BQ-9000 certified biodiesel marketers, agree to meet ASTM standards for biodiesel as well as special handling steps to ensure delivery of an on-specification product. Participants undergo various audits to maintain their accreditation or certification.

Appendix A: Engine and Vehicle Manufacturers' Positions on Biodiesel

Introduction

It has only been a few years since biodiesel blends started becoming more widely available in the U.S. Engine and vehicle manufacturers are not all in agreement on what level of biodiesel is appropriate. Most permit the use of B5 (95% conventional diesel/ 5% biodiesel). Some permit the use of B20 (80% conventional diesel/20% biodiesel) at least in their newer engines and vehicles. Most do not yet permit the use of blends higher than B20. This appendix provides information on the position of various manufacturers on the use of biodiesel. This information has been compiled from various sources including company position statements or press releases, technical bulletins and the fuel recommendations section of owners' manuals. In many cases the information is excerpted from its source, and it should be noted that manufacturers may also have recommendations for other fuel parameters such as cetane number, the use of additives (or restriction on such use), fuel filter requirements and other fuel-related issues.

Editor's note: The information in Appendix A has been reprinted verbatim from the manufacturers' source material.

Mercedes-Benz Position on Biodiesel

As of January 19, 2007

Mercedes-Benz USA now approves the use of B5 biodiesel (standard diesel with a maximum 5% biodiesel content) in all Common Rail Injection Diesel "CDI-engines" - including BLUETEC engines. As biodiesel can be refined from a variety of raw materials resulting in widely varying properties, the only approved biodiesel content is one that meets the ASTM D 6751 specification and that has additionally the necessary oxidation stability (min. 6h, proved with EN14112 method) to prevent damages to the system from deposits and/or corrosion.

Please ask your service station for further information. If the B5 biodiesel blend is not sufficiently labeled to clearly indicate that it meets the above standards, please do not use it. The Mercedes-Benz limited warranty does not cover damage caused by the use of fuels not meeting Mercedes-Benz approved fuel standards.

Volkswagen of America, Inc.
Volkswagen of America Statement – Biodiesel Fuel (Excerpt)

As a result of a major joint research project between the Volkswagen Group and the prominent agricultural products firm Archer Daniels Midland Company, and improvements in the specifications for biodiesel fuel in North America, Volkswagen has determined that diesel fuel containing up to five percent biodiesel meets the technical specifications for Volkswagen vehicles equipped with TDI engines imported to the United States. Therefore, the diesel fuel commonly known as "B5 biodiesel" is acceptable for use in all our TDI vehicles.

Volkswagen hopes that by approving B5 biodiesel for usage in our TDI vehicles, we will encourage biodiesel development and increase the biodiesel industry's role in developing high quality renewable fuels for motor vehicles. This, combined with the exceptional fuel economy that Volkswagen TDI owners already experience, has the potential to be a small part of the energy independence we all seek. Volkswagen sees biodiesel as a key element of a comprehensive long-range fuel strategy that relies on efficient, clean diesel technology and the use of an increasingly broad portfolio of renewable fuels.

We do want to take a moment to speak to you about fuel quality. While this historic decision by Volkswagen is a first step in a renewable fuel strategy for our cars, it is not a departure from our strong recommendation that you use only high-quality fuel, nor from our long-standing fuel requirements for warranty purposes, whether diesel, biodiesel, or gasoline. We will continue to view fuel issues in the same fair manner as we always have in the past, but we must stress that vehicle damage that results from misfueling or from the usage of substandard or unapproved fuels cannot be covered under our vehicle warranties.

Volkswagen recommends that you use standard diesel fuel, or biodiesel blend fuels of up to five percent (B5), purchased from a mainstream retailer through a commercial pump. Should the use of

substandard fuels, or higher level blends of biodiesel, damage your engine or fuel system, such damage cannot be covered under warranty. If a fuel problem related to substandard diesel fuel or biodiesel blend fuel occurs with your vehicle, you may be asked to provide the source or sales location of the fuel.

In summary:

1. Volkswagen recommends the use of standard diesel fuel or commercially supplied biodiesel blends of no more than five percent ("B5") biodiesel.
2. Never use any fuel, whether diesel, B5 biodiesel, or otherwise, that fails to meet the latest petroleum industry specifications or that is not purchased from a commercial retail diesel pump. If you are unable to determine whether a particular fuel blend is B5 biodiesel that meets the latest biodiesel industry specifications, ask your service station for more information.
3. Never use any fuel for which the contents cannot be identified.

Ford Motor Company Position (Excerpt)
https://www.fleet.ford.com

Fuels containing no more than 5% biodiesel may be used in Ford diesel powered vehicles. Consistent with WWFC (World-Wide Fuel Charter) category 1-3, "Fatty Acid Methyl Esters (FAME) used in commercial fuel must meet both the EN 14214 and ASTM D 6751 specifications".

There are still some unresolved technical concerns with the use of biodiesel at concentration greater than 5%. Some of the concerns are:

- Requires special care at low temperatures to avoid excessive rise in viscosity and loss of fluidity
- Storage is a problem due to higher then normal risk of microbial contamination due to water absorption as well as a higher rate of oxidation stability which creates insoluble gums and sediment deposits
- Being hygroscopic, the fuel tends to have increased water content, which increases the risk of corrosion
- Biodiesel tends to cause higher engine deposit formations
- The methyl esters in biodiesel fuel may attack the seals and composite materials used in vehicle fuel systems
- It may attack certain metals such as zinc, copper based alloys, cast iron, tin, lead, cobalt, and manganese
- It is an effective solvent, and can act as a paint stripper, whilst it will tend to loosen deposits in the bottom of fuel tanks of vehicles previously run on mineral diesel

Ford believes that it is unlikely that the emission benefits of biodiesel will be sufficient to achieve Tier 2 emission standards with out catalysts and particulate filters. Ford is working aggressively on technologies, including engine improvements, new catalysts and particulate filters that will remove HC, CO, NO_x and soot from diesel exhaust. Renewable fuels or blends containing renewable components can help reduce the total lifecycle CO_2 impact and may be used when available, but they are not the key step to achieving Tier 2 emission standards.

General Motors Corporation
Another Choice For Fleets (Excerpt)

Beginning with the January 2004 production cycle, GM's Duramax Diesel engines will be approved for B5, a blend of 5% biodiesel fuel, giving fleets another choice for fueling and for complying with state and federal requirements.

Cummins
Frequently Asked Questions

The Use of B20 Biodiesel Blends in Cummins Engines.

1. What Cummins engines can be used with B20 biodiesel?

The current approved engine models are as follows:

On-Highway: ISX, ISM, ISL, ISC and ISB engines certified to EPA '02 and later emissions standards, and ISL, ISC and ISB engines certified to Euro III

Off-Highway: QSX, QSM, QSL, QSC, QSB6.7 and QSB4.5 engines certified to Tier 3/Stage IIIA, QSM Marine and QSM G-Drive

2. *What are the general fuel specification requirements?*

B100 biodiesel must conform to the American Society of Testing Materials (ASTM) specification - ASTM D6751. ASTM D6751 has been revised to now include a stability requirement which was not included in the previous specification. This is a critical requirement when B100 is blended with petrodiesel to produce a B20 blend.

B20 needs to conform to the Engine Manufacturers Association (EMA) recommended test specification for B20. There is currently no ASTM specification for B20 blends. It is expected that ASTM will issue a specification for B20 in the near future.

In Europe, specifications for biodiesel are issued under EN 14214. EN 14214 is published by CEN, the European Committee for Standardization or Comité Européen de Normalisation. http://www.cen.eu/cenorm/index.htm

Customers are required to purchase the biodiesel blend from a BQ-9000 Certified Marketer. The B100 fuel used in the blend must be sourced from a BQ-9000 Accredited Producer. BQ-9000 Certified Marketers and Accredited Producers can be found at www.bq-9000.org.

3. *Where can I find further information as it relates to the use of biodiesel in Cummins engines?*

Cummins has recently updated the Fuels Requirements - Service Bulletin. The bulletin number is 3379001-11. It can be obtained on Cummins QuickServe web site at quickserve.cummins.com.

4. *Are there any special requirements for fuel filters?*

Cummins requires the use of a StrataPore™ fuel filter media and strongly recommends using Cummins Filtration filters equipped with StrataPore media. If StrataPore media is not used, then an equivalent filter that meets specific performance standards must be used. For more information, please visit www.cumminsfiltration.com.

5. *Do I need to modify any service intervals when switching from petrodiesel to biodiesel?*

Due to the solvent nature of biodiesel and the potential for “cleaning” of the vehicle fuel tank and lines, new fuel filters must be installed when switching to biodiesel on used engines. Fuel filters will need to be replaced at half the standard interval for the next two fuel filter changes. After this initial period, you may revert to the intervals specified in your Operation and Maintenance Manual. For 2007 on-highway MidRange engines only, oil sampling will be necessary for the first six months of operation with biodiesel to monitor fuel dilution of the lubricating oil.

6. *Are there any biodiesel fuel storage guidelines?*

Use biodiesel fuel within six months of its manufacture. Biodiesel has lower oxidation stability compared to petrodiesel. Avoid storing equipment with biodiesel blends in the fuel system for more than three months.

7. *What materials are incompatible with biodiesel?*

Natural rubber, nitrile and butyl rubber are particularly susceptible to degradation. Also, copper, bronze, brass, tin, lead and zinc can cause deposit formations. The use of these materials and coatings must be avoided for fuel tanks and fuel lines.

Note: Contact your vehicle manufacturer to determine if any of the OEM-supplied components are at risk with biodiesel in order to prevent engine or vehicle damage.

8. *Why didn’t Cummins include engines prior to 2002?*

The main reason not to include engines earlier than 2002 is due to materials compatibility concerns. Some fuel systems in pre-2002 engines contain components that are not compatible with a B20 biodiesel blend. 2002 and later engines contain fuel system components that are compatible.

9. *How does using biodiesel affect the engine warranty?*

Cummins engine warranty covers failures that are a result of defects in material or factory workmanship. Engine damage, service issues and/or performance issues determined by Cummins to be caused by the use of biodiesel fuel not meeting the specifications outlined in the Fuels Requirements - Service Bulletin (3379001-11) are not considered to be defects in material or workmanship, and are not covered under Cummins engine warranty.

This is no different from Cummins position with any regular diesel fuel. Cummins does not cover the damage caused by products from other companies that may have insufficient quality. It is important to ensure when using any diesel fuel or a B20 biodiesel blend with a Cummins engine that the fuel meets industry acceptable quality standards.

10. *What are the implications to emissions certification?*

It should be emphasized that Cummins, in common with all other engine manufacturers, only certifies engines to meet the prescribed EPA (or other local regulatory agency) registered fuels. It is the customer's responsibility to use the correct fuel prescribed by these regulations and as recommended by the engine manufacturer.

The EPA has regulated the United States highway diesel fuel quality since 1993 to ensure that it is compatible with engine emissions standards and air quality goals. It is the responsibility of the customer to obtain the proper local, regional or national exemptions required for the use of biodiesel in any emissions-regulated Cummins engine.

11. *Will Cummins support the use of B20 biodiesel in engines not listed in this document?*

Cummins fully supports the use of environmentally beneficial alternative fuels. All of our automotive and industrial engines are compatible with B5 biodiesel to help encourage the greater use of renewable, domestically grown fuel.

Cummins is continuing the evaluation of biodiesel concentrations higher than 5 percent for many more of our products such as our A Series, B3.3 and QSB3.3 as well as our High-Horsepower engines. We are aware of the growing interest in B20 fuel blends and fully support this interest in renewable fuels. As we reach conclusions and the completion of these evaluations, we will modify our position on engine compatibility accordingly.

Some OEMs using Cummins engines not listed in this bulletin may have specific releases regarding the use of biodiesel that apply only to their application. Consult the OEM if in doubt.

12. *Is B20 approved for the Dodge Ram Turbo Diesel?*

For Cummins engines in Dodge Ram trucks, biodiesel fuel can be blended with an acceptable diesel fuel up to a 20 percent volume concentration (B20) for municipal, government and commercial fleets only. This applies to selected model year vehicles. Please consult DaimlerChrysler for specific requirements and approved vehicle models.

Case IH

Biodiesel: What You Need to Know Now

(Excerpt from Case IH Web site)

Diesel fuel blended with biodiesel is drawing wider interest as an alternative fuel. Farm equipment manufacturers, including Case IH, endorse the use of it, and various regulatory agencies even requirie biodiesel use. A Minnesota directive mandates that diesel fuel sold in that state contains at least 2% biodiesel (B2).

Biodiesel is often blended with diesel fuel by fuel distributors. The most common blends are B2, B5 or B20. Pure 100% biodiesel (B100) can also be used unblended as a fuel in some diesel engines.

To determine the maximum biodiesel blend appropriate for your machine, review the product sections of this Web site. Biodiesel ratings by model appear in the left column. Biodiesel is a diesel fuel replacement manufactured from vegetable oils, recycled cooking greases or oils or animal fats. Soybeans are a primary source for biodiesel.

Biodiesel blends are proving to reduce emissions,

improve fuel lubricity and reduce fossil fuel demands while creating new demand for soybeans.

Currently, commercial biodiesel production and distribution is located primarily in the Midwestern United States. Whether you use it voluntarily or because it's mandated, there are a few things you need to be aware of.

Storage issues

As an organic material, diesel fuel is a food source for various types of microbes that feed and grow at the fuel/water interface. Water works its way into storage systems from humidity, condensation, etc.

Because on-farm fuel supplies are used fairly quickly (rather than stored unused for months), algae and other types of organic growth haven't been much of an issue with pure diesel fuel.

However, biodiesel is a richer food source. It is more highly oxygenated, and presents more interfaces with water. This microbial activity creates sludge that can plug filters.

Similarly, biodiesel can have a cleaning effect that loosens accumulated sediment in storage tanks and equipment tanks. Although the U.S. Department of Energy says that "B20 is sufficiently diluted so that most (cleaning effect) problems are insignificant," field reports indicated this is a possibility even with the B5 blends, especially if your fuel storage and handling systems are old or have not been carefully maintained.

So what should you do to successfully use biodiesel? Basically, remember the old adage, "Use clean fuel. Keep it clean."

1. Purchase your biodiesel blend from a trusted fuel supplier.
2. Treat your storage tanks for moisture with a moisture dispersant. A biocide is recommended.
3. Add or upgrade in-line filters.
4. Add a fuel/water separator.
5. Take steps to minimize in-tank condensation, by keeping tanks topped off.
6. If your on-farm fuel storage system is due for replacement, adopting biodiesel can be a good reason to do so.

Take similar steps to clean and protect equipment fuel systems. Be prepared to replace fuel filters more often, especially in the early stages of your biodiesel blend usage. Fuel filters for current diesel engines are very efficient, but they cannot do their job if they become overloaded with contaminants.

Biodiesel blends, especially B2 and B5, appear to be good alternatives to pure diesel fuel and improve lubricity and emissions.

While B100 biodiesel contains about 8% less energy per gallon than No. 2 diesel, the U.S. Department of Energy says that blends of B5 or less "do not cause noticeable differences in performance compared to No. 2 diesel." B20 blends, the department says, will lose only 1% to 2% in power, torque and fuel economy. Using pure B100 can reduce power and torque by 4% to 7%.

Case IH Engine Biodiesel Blend Statement

Case IH fully supports the use of B5 blends in all current and past engines for Case IH agricultural equipment, as well as B20 in more than 90% of the models now being sold in Europe and North America, including Magnum™ tractors. Nearly half of the models sold globally, including the flagship Axial-Flow® 8010 combine, are approved following proper protocols for B100. Your local Case IH dealer has all the details on specific technical requirements for use.

Take a look at the left-hand column of the individual product pages on this Web site, or consult your Case IH dealer to determine which blends are approved for your equipment.

Biodiesel used in Case IH engines must meet the requirements of U.S. standard ASTM6751 or European standard EN14214. When using blends greater than B5 (B6-B100), certain handling and maintenance requirements come into play, and customers are advised to speak with their dealers for the specific recommendations covering their biodiesel blend of choice.

Case IH is committed to working with its partners to push toward higher-level biodiesel that will be a compatible fuel source in future low-emissions compliant engines. Case IH continues the aggressive field tests to evaluate performance with B100 on those engines not yet approved.

General Biodiesel User Guides:

* Use biodiesel from a trusted source that is a BQ-9000 accredited producer or certified marketer/distributor. Preblends are recommended over on-farm blending, which can result in a non-homogenous mixture.
* Use storage tanks that are clean and free of sediment.
* Avoid copper, brass, lead, tin and zinc in tanks and fittings.
* Minimize water forming through condensation by keeping tanks topped off.
* Use a biocide in primary storage tanks.
* Add fuel filters and water separators on your primary storage tank.
* Follow recommended maintenance schedules for equipment fuel filters and water separators. Expect to change filters more frequently, especially during the early stages of biodiesel blend use.

User Guides for Blends of B6 through B20:

* Follow the General Biodiesel Guides.
* Check your engine oil level daily. If the oil level increases contact your Case IH dealer.
* Use B6 through B20 only if the outside temperature is greater than 16 degrees F (-9 degrees C).
* Clean up biodiesel spills immediately to avoid paint damage.
* Avoid storing equipment more than three months with biodiesel in the fuel system, due to potential stability problems with biodiesel. If necessary, run the engine on pure diesel fuel for 20 to 30 minutes to flush the biodiesel out of the system.
* Avoid storing biodiesel in on-site fuel tanks for longer than 3 months.
* The oil and filter change interval for electronic NEF and Cursor engines using a high pressure common rail fuel system is reduced to 300 hours. See your operator's manual.

User Guides for Biodiesel Blends Greater than B20:

* Follow the General Biodiesel Guides and those for Blends B6 through B20.
* Use greater than B20 blends only if the outside temperature is greater than 41 degrees F (5 degrees C).
* Keep biodiesel storage tanks protected from direct sunlight or frost.
* The use of blends of 20% biodiesel (B20) or more requires greater attention to fuel quality and handling, additional vehicle maintenance and service, and in some cases an update kit is necessary to make your machine greater than B20 compatible.
* Visit your Case IH dealer, who will provide the details of the special requirements for your equipment and request your agreement to meet them.

Fuel Treatment

Biodiesel blends are more prone to microbial growth than straight diesel fuel.

Case IH dealers carry fuel treatments that prevent microbial growth and the resulting slime that can clog filters. These include Fleetguard's Fleet-tech Microbicide and a Valspar fuel additive (part number B50546, 16 ounce, or part number B50547, 23 ounce).

Mack Trucks, Inc.

Service Bulletin Number SB 210043 Date 6/28/07
Model E Tech™ ASET ™, MP7, MP8 (Excerpt)

Use of Biodiesel Fuel in Mack Diesel Engines – E Tech™, ASET™, MP7 and MP8 Engines

Does not apply to Mack Trucks Australia

Mack Trucks, Inc. Approval of BioDiesel Products:

The only BioDiesel fuel approved by Mack Trucks, Inc. for use in E-Tech™, ASET™, MP7 (both US04 and US07 emission-compliant) and MP8 engines is Soy Methyl Ester (SME or SOME) in blends up to a B5 concentration (5% blend).

NOTE

Although higher concentrations are available, concentrations up to B5 (maximum) are the only blends currently approved by Mack Trucks, Inc.

NOTE

MACK engines are certified to comply with U.S. EPA and California Air Resources Board (CARB) emissions standards based on the use of reference test fuels commonly available in the United States and specified in the Maintenance and Lubrication Manual, TS494. Use of alternative fuels, including BioDiesel, may affect engine emissions. Mack Trucks, Inc. does not warrant, and is not responsible for ensuring that the engines will comply with U.S. EPA and CARB emissions standards when operated on fuels not specified by Mack Trucks, Inc.

Warranty Policy:

The engine warranty covers defects in material and workmanship on the part of the manufacturer. Failures caused by fuel are not warrantable.

ASTM Standards:

The American Society for Testing and Materials (ASTM) standard D 6751 defines B100 BioDiesel. Any B100 product used in the manufacture of the blend intended for use in a MACK vehicle must conform to the ASTM D 6751 standard.

ASTM standard D 975 defines the minimum accepted values for the properties of petroleum-based diesel fuel. Any petroleum-based diesel fuel used in a MACK vehicle, either alone or when blended with B100 BioDiesel for the maximum approved concentration (up to B5), must meet the ASTM D 975 standard.

Certified BioDiesel Required:

The National BioDiesel Accreditation Commission conducts quality certification and accreditation programs for producers and marketers of BioDiesel products. For details on these programs, visit the BQ-9000 Quality Management Program web site at www.bq-9000.org. The B100 BioDiesel used in the approved blend must be produced by a BQ-9000 Accredited Producer and the blend must be supplied by a Certified Marketer.

Storage of BioDiesel:

The standard storage and handling procedures used for petroleum-based diesel fuel apply to BioDiesel (reference the Maintenance and Lubrication Manual, TS494, for information concerning the handling and storing of diesel fuel). Compared to petroleum-based diesel fuel, BioDiesel fuel has lower oxidation stability, and there are greater concerns for water contamination and microbial growth. BioDiesel should be stored in a clean, dry, dark environment. Acceptable storage tank materials include aluminum, steel, fluorinated polyethylene, fluorinated polypropylene or Teflon®. Storage containers which contain copper, brass, lead, tin or zinc should not be used. Every effort should be taken to make sure that the BioDiesel product is used within six months of the date of manufacture.

Fuel Filter Change Intervals:

BioDiesel has solvent qualities better than those of petroleum-based diesel fuel. Because of this, BioDiesel will break down petroleum-based diesel fuel residuals found on the insides of fuel tanks, fuel lines, etc., and as a result, fuel filters will become clogged with particulates. It is recommended that fuel filters be changed at half the normal interval for the first two filter changes when the transition to BioDiesel fuel is made. After that, the standard specified filter change intervals can be used, or shorter intervals if a reduced filter change interval was being used prior to the changeover to BioDiesel.

Detroit Diesel Corporation

Diesel Fuel Recommendations (dated 10/05)

(Excerpt)

5.1.4 BIODIESEL FUELS

Biodiesel fuels are alkyl esters of long chain fatty acids derived from renewable resources. Detroit Diesel Corporation highly recommends biodiesel fuels made from soybean or rapeseed oil through the proper transesterification reaction process. Other feedstock source of biodiesel fuels such as animal fat and used cooking oils are not recommended by DDC. Biodiesel fuels meeting ASTM D 6751 specification, prior to blending can be mixed up to 5% maximum by volume in petroleum die-

sel fuel. The resulting mixture must meet the fuel properties listed in Table 5-1 *(of these recommendations)* and ASTM D 975 specification. Failures attributed to the use of biodiesel fuel will not be covered by Detroit Diesel product warranty. Also, any engine performance problem related to the use of biodiesel fuel would not be recognized nor considered DDC's responsibility.

International Truck and Engine Corporation

Technical Service Information TSI –05-12-21
Date May 2005 Subject Biodiesel Fuels (Excerpt)
Engine Family: All Diesel Engines, Except Green Diesel Technology™
(Ultra Low Sulfur Fuel Only)

Description:

International's stated opinion on the use of biodiesel follows the official position of the Engine Manufacturers Association (EMA) on biodiesel fuel. Refer to the following website for further information (www.enginemanufacturers.org).

Low Biodiesel Blends (up to 5%)

The properties of these blends are within diesel specification limits and meet the ASTM D 975 Diesel Standard. All blends up to B5 biodiesel should not cause engine or fuel system problems. International Truck and Engine Corporation will warranty engines using fuels up to and including the B5 blend.

Higher Biodiesel Blends (greater than 5%)

The characteristics of higher biodiesel blends are not within ASTM D975 diesel specifications. A blend of 20% biodiesel and diesel fuel (B20) is typically used in commercial fleets that are subject to environmental concerns in the urban environment. Work is underway within ASTM to issue a specification for B20. Until then, the user must rely on the fuel supplier to properly blend the components and insure quality.

B100 (neat biodiesel) is generally not recommended for use in engines. Special uses of B100 are considered (such as in National Parks), but these are the exception from common commercial applications. B100 biodiesel costs more than diesel fuel and its availability is limited.

International Truck and Engine Corporation's stated warranty policy does not deny warranty coverage solely for the use of higher biodiesel blends, but only if the failure is attributed to higher biodiesel blends.

Engine Performance and Durability of B100 and High Biodiesel Blends

- Maximum power output using B100 is reduced by 5-7%.
- Low temperature viscosity of biodiesel is higher than viscosity of diesel fuel and some flow impairment may occur in fuel filter and lines.
- Elastomers and various seal materials may harden or swell. Sealing materials must be monitored when using biodiesel blends, especially in older engines.
- Thermal and oxidative stability of biodiesel blends is inferior to that of diesel fuel. In general, fleets fueled by B20 must consume their fuel blend inventory within a 6 month period.
- Water separation efficiency when operating with higher biodiesel blends is inferior to that of conventional diesel fuel. This may lead to corrosion of engine fuel supply and fuel injection hardware. Furthermore, water may combine with biodiesel Fatty Acid Methyl Esters (FAME) to create acids that greatly accelerate corrosion.
- The use of higher biodiesel blends may reduce the engine oil service life and drain interval. Oil sampling and analysis may be used to determine the effect on engine oil service life.

Fuel Tank Care

Any residue or microbial growth in the tank will compound with the use of biodiesel. This can cause serious plugging of filters and deposits in the fuel system. Fuel tanks should be thoroughly cleaned and dried before operating with any biodiesel blends. Adding biocides will help minimize growth.

Volvo Truck Corporation

Service Bulletin Date 6/98 Group 170 Version 01
(Excerpt)

Biodiesel/RME

Vegetable oils and/or esters of vegetable oils, also called "biodiesel", such as for example rape

methylester (RME) are available on certain markets both as in its pure state and as a mixture in diesel fuel.

Volvo Truck Corporation does not accept more than 5% RME in diesel ready mixed from the oil company since nitric oxide emissions increase drastically and the injection system can be damaged. Volvo does not intend carrying out long-term tests on engines for these fuels as no standard exists. If, in spite of this, the customer wishes to use fuels based on vegetable oils, we recommend that the oil changing intervals be halved in order to eliminate the risk of dilution of the engine oil. It is oil companies who are responsible for ensuring that the mixture of biodiesel meets the diesel standards. The customer must not add mixtures in the biodiesel in the diesel tank afterwards.

The cold properties for these fuels are not particularly good. Pure REM can produce deposits already at -10°C. They even have washing like characteristics which causes faster clogging of the fuel filters.

UD Trucks
Distributed by
Nissan Diesel America, Inc.
Press Release 8/14/06 (Excerpt)
B5 Biodiesel

Irving, TX, August 4, 2006: Nissan Diesel America, Inc. Service Operations has listed "B5" as an approved fuel for the UD Truck line. B5 is a blend of 95% petroleum diesel and 5% biodiesel, the approved fuel must conform to the ASTM D 6751 standard.

John Deere
Guidelines of Biodiesel Fuels used in Diesel Engine – Updated February 6, 2007 (Excerpt)

What is & isn't Biodiesel

A fuel comprised of mono-alkyl esters of long chain fatty acids (known as Fatty Acid Methyl Esters or FAME) derived from vegetable oils or animal fats, officially designated as B100 or 100% Biodiesel in compliance with ASTM D6751 (USA) or EN 14214 (Europe) industry specifications. The standard manufacture process to make biodiesel is called **transesterification**.

Soybean Methyl Ester – SME, predominantly in USA
Rapeseed (or Canola) Methyl Ester – RME, predominantly in Europe
Palm Methyl Ester – PME, predominantly in Asia

Other feedstocks include but not limited to:
Animal Fats (beef tallow, pork lard)
Yellow Greases (waste cooking oil or recycled greases)
Cotton Seed
Sunflower Seed
Coconut Oil
Sesame Seed

Biodiesel blended with regular diesel fuel is named Biodiesel Blend, designated as BXX (B2, B5, B20, etc.) where XX is the volume percent of biodiesel used in the blend.

NOTE: Raw pressed / partially refined vegetable oils or recycled greases that have not been processed into biodiesel through **transesterification** are NOT biodiesel and Must Not Be Used in any form or concentration.

Biodiesel Advantages

- Renewable energy alternative, biodegradable & nontoxic
- Reduce dependency on petroleum imports
- B2 level provides significant lubricity improvement
- High cetane, zero aromatics, and minimal sulfur content
- Lower engine PM, HC, CO and life-cycle CO_2 emissions
- Less visible smoke

Biodiesel Technical Challenges

- Increased engine NO_x emission
- Cold weather flow degradation
- Stability & storage issues (moisture absorption, oxidation, microbial growth)
- Hygroscopic nature impacts filtration system (water separator efficiency reduction)
- Thermal degradation at elevated temperatures
- More crankcase dilution caused by higher fuel density & viscosity
- Elastomer seal, gasket, and other material compatibility (Cu, Pb, Zn, and Sn)

- Lower energy content (less power & fuel economy)
- Property variation due to different feedstocks
- Higher cost if there were no government tax incentive

Deere Recommendation

Biodiesel blend up to B5 (5% biodiesel mixed with regular petrodiesel by volume) can be used in John Deere diesel engines, provided that the neat biodiesel or B100 meets ASTM D 6751 (USA) or EN 14214 (Europe) specification as shown in Table A. Furthermore, the petrodiesel portion should meet the requirements of ASTM D 975 (USA) or EN 590 (Europe) commercial standards. Deere also requires that biodiesel and its B5 blend to be purchased from a BQ-9000 accredited producer or BQ-9000 certified marketer / distributor.

We must make certain that our decisions about biodiesel usage and the effect on machine performance are based on factual test experience. Deere is a responsible biodiesel supporter and understands the future prosperity of biodiesel industry rests on product quality control, field customer appreciation, long-term supply and distribution.

Biodiesel blend above B5 could have increasingly more performance issues. The higher the biodiesel concentration, the more likely the risk associated with its negative aspects. There is no industry standard to regulate the quality & performance of biodiesel blend at this time. In particular, certain properties of biodiesel blend may deviate significantly from its B100 and petrodiesel constituents (synergism or antagonism) and could manifest a highly nonlinear relationship. The following shall be observed during routine practice.

Fuel Quality Assurance

- Ensure the quality of B100 and biodiesel blend (right concentration, uniform mixture)
- One-time splash blending in an immobile tank is inadequate for homogeneous mixing
- Recommend in-line (or proportional) blending to achieve good mixture
- B100 should be kept warm prior to blending in the winter to preclude wax formation
- Keep storage and vehicle tanks as full as possible to minimize moisture condensation
- Monitor water content and microbial growth of the biodiesel fuels regularly
- Sampling fuel periodically to confirm the % level of biodiesel is consistent
- Limit the storage tanks from extreme temperature exposure (direct sun or frost)
- Storage life should be reduced accordingly (one year for B2, six months for B20, etc.)
- Buy fuel from a BQ-9000 accredited producer or a BQ-9000 certified marketer

Vehicle Maintenance Protocol

- Drain and clean fuel storage tank before and after using biodiesel
- All tank caps and covers shall be installed properly to prevent water from entering
- Clean spills immediately to avoid paint corrosion if using B20 or higher blends
- Fuel filter may need to be replaced more often initially due to premature plugging for that biodiesel is a minor solvent capable of removing deposits within the fuel system
- Wax formation of biodiesel in cold environment may also cause filter plugging, use lower blends or better yet 100% petroleum diesel during the winter or storage period
- Check engine oil sump level daily prior to starting, a rising level may indicate crankcase fuel dilution and need for oil change (biodiesel is less stable)
- Switch to regular diesel for extended periods of storage / idle of the vehicle

Performance Related Issues

- Power loss, and in some instances dangerous power (fueling rate) growth, from B100 or other high concentration biodiesel blends
- Higher biodiesel blend may cause leakage in seals and hoses of Buna-N, Nitrile and natural rubber, use fluorocarbon or Viton type of materials instead which are compatible with biodiesel

- Corrosion of fuel injection equipment particularly for higher biodiesel blend
- Injector nozzle deposits from B20 or higher biodiesel blend
- Lacquering and seizure of internal injection system components
- Injection pump failure caused by water ingestion
- Formation of sludge and sediments
- Reduced engine service life

Consult fuel supplier for additives to improve storage and performance of biodiesel.

Suggested type of additives would be:

- Oxidation stabilizer
- Cold flow enhancer
- Micro biocide

High pressure common rail (HPCR) and rotary fuel injection pumps are most sensitive to biodiesel usage with regard to deposit formation. When using higher biodiesel blend or B100 in a rotary fuel injection pump, the engine oil level must be checked daily if the ambient temperature is -10ºC (14ºF) or lower. If oil becomes diluted with fuel, oil change intervals must be shortened. Correct oil service intervals may be established by using OilScan or OilScan Plus programs. Another factor due to cold temperature is the Cloud Point (CP) where wax crystals start to form which makes the fuel cloudy, or Cold Filter Plugging Point (CFPP) where wax crystals have grown to some threshold size beginning to plug the filter. Biodiesel demonstrates relatively high CP or CFPP as compared with petroleum diesel fuel.

Our product warranty only covers defects in material and workmanship as manufactured and sold by John Deere. Failures caused by the use of poor quality fuels, be that biodiesel or regular petroleum diesel, are not defects of material and/or workmanship as supplied by John Deere, hence cannot be compensated under our warranty. On the other hand, using biodiesel blends above B5 does not automatically void warranty. Users of John Deere emission certified engines are responsible for obtaining the proper local, state, and national exemptions required for the use of biodiesel.

Emission certified engines are equipped with fuel injection pumps (FIP) that are compatible with biodiesel blends up to B5 maximum in accordance with the common position statement from diesel fuel injection equipment (FIE) manufacturers.

NOTE: Experience shows that biodiesel is not always conforming to the established standards. Furthermore, the specifications listed in Table A are broadly defined which results in variation of the biodiesel quality. It should be clarified that ASTM D 6751 is recommended for blending up to B20 maximum in USA, whereas EN 14214 can be used as a commercial RME B100 fuel in Europe. The B100 composition may change appreciably due to different feedstocks. This quality variation could cause fuel injection system malfunction particularly with wide range of engine design and operating conditions seen in the field. That is why FIE manufacturers, John Deere and Engine Manufacturers Association in general recommend B5 maximum for the time being. Operator must ensure the supply of good quality biodiesel that will not harm any parts of the engine fuel system. To that extent, we require that the biodiesel (B100) and blended biodiesel (B5) be purchased from a BQ-9000 accredited producer or BQ9000 certified marketer / distributor. For regular petroleum diesel its energy content is usually proportional to the level of fuel density and/or aromatics. This rule cannot be applied to biodiesel blends due to opposite trends existed from biodiesel with higher density and lower energy content.

John Deere has developed its own global standards of B100 and B20 for testing purposes with additional requirements such like thermal and oxidation stabilities, among others.

New Holland

Press Release: May 17, 2006

New Holland Leads the Biodiesel Revolution

(Excerpt)

New Holland, Penna. (May 17, 2006) – New Holland today informed the National Biodiesel Board (NBB) it fully approves use of up to B20 blends (20% biodiesel/ 80% petroleum-based diesel) on all equipment currently produced with New Holland engines.

Biodiesel is a renewable fuel produced from oilseed crops, primarily soybeans in the United States and canola in Canada, and animal fats. It can be blended with conventional diesel. The biodiesel must meet the specified industry standard for fuel quality of ASTM D6751 to ensure optimum performance and durability of the engine.

New Holland strongly recommends the use of approved fuels and compliance with strict handling, storage and maintenance requirements to maintain the integrity of the fuel.

The necessary technical advice and specific maintenance programs are available through New Holland's expert dealer network to ensure the biodiesel is handled properly and critical areas such as fuel hoses and injectors receive further inspection so customers can confidently work with high-quality B20 biodiesel blends without compromising the machine's performance or durability. The biodiesel industry has also instituted a voluntary fuel quality program called BQ-9000 for biodiesel producers and marketers.

Kubota Tractor Corporation

Kubota Approves Use of B5 Biodiesel Fuels in Kubota Diesel Products

November 1, 2006 (Excerpt)

Kubota Tractor Corporation (KTC) announces a global Kubota decision to approve the use of "B5" biodiesel fuels in specified Kubota diesel-powered products. Biodiesel fuels, most often offered in a blended-petroleum format, are derived mostly from vegetable oils, and are offered in the United States as an alternative source for energy.

Biodiesel Fuel (BDF) blended with diesel fuel may be used in the Kubota diesel powered products listed below only if the blended fuel meets the following conditions:

1. BDF concentration must not exceed 5% by volume (B5 blend). Greater concentrations increase the likelihood of corrosion and failure of the aluminum, zinc, rubber, and plastic parts of the fuel system.
2. The petroleum diesel fuel base must meet the American Society for Testing and Materials (ASTM) D975 fuel specification (or the European EN590 specification). The pure biodiesel base must meet minimum requirements provided by ASTM D6751 (or EN14214) prior to blending. Raw pressed vegetable oils are NOT acceptable for use in any concentration.
3. Kubota strongly recommends that B5 blend be purchased from a BQ-9000 accredited producer or certified marketer. Kubota discourages local blending of BDF, because it is difficult to meet the quality requirements explained above.
4. Users of Kubota Emission Certified Engines are responsible for obtaining any required local, state, or national regulatory approvals for the use of BDF.

Enhanced engine care may be required even if the fuel meets the above standards. Kubota has the following concerns and recommendations regarding the use of B5 blend:

1. B5 blend attracts moisture and may contain higher water content than conventional diesel fuels. Keep storage and vehicle tanks as full as possible and ensure all caps and covers are installed properly to prevent water from entering and collecting in the fuel system.
2. Follow the oil change intervals recommended by Kubota in your operator's manual. Extended oil change intervals may result in premature wear or engine damage.
3. B5 blend is biodegradable and degradation of the fuel supply is accelerated by the presence of water, oxygen and other impurities.
   - To avoid damage caused by fuel degradation, B5 blend should not be used if it has been stored for more than 3 months.
   - If an engine is going to be placed in storage, the B5 blend should be flushed out by operating the engine for at least 30 minutes on conventional diesel fuel.
4. In consideration of the particular properties of BFD it is very important to follow the maintenance interval and procedures regarding the fuel system as specified in the operator's manual.
   - Microbial contamination and growth may cause corrosion in the fuel system and frequent plugging of the fuel filter.

- Cold weather conditions can lead to fuel system plugging, hard starting or other problems.
- BFD attracts moisture and may contain higher water content than conventional diesel fuels.

5. B5 blend will damage painted surfaces. Clean up spills immediately.
6. Tampering with the factory adjustments on fuel system components is a violation of EPA regulations, and can result in denial of warranty coverage.

Kubota's statement of allowance to use B5 blend in no way changes the published warranty terms and conditions. Fuel system failures that can be attributed to the quality of fuel used are ineligible for warranty coverage. Please see your local Kubota dealer for more information.

Listing of Kubota Products Approved for Use with Biodiesel

BX1500, BX1800, BX2200, BX1830, BX2230, BX1850, BX2350, BX22, BX23, BX24

B7410, B7510, B7610, B7800, B2630, B3030, B21, B26

L2800, L3400, L4400

L3130, L3430, L3830, L4330, L4630, L5030

L3240, L3540, L3940, L4240, L4740, L5240, L5740

L39, L48

MX5000, M4900, M5700, M4800SU, M6800, M8200, M9000

M5040, M6040,M7040, M8540, M9540, M96S, M108S

M95S, M105S, M105X, M125X, M108X, M110, M120

M95S, M105S, M105X, M125X, M108X, M110, M120

G2160, GR2100, GF1800, F2880,F3680, F2260, F2560, F3060

ZD18, ZD21, ZD25, ZD28, ZD321, ZD326, ZD331

RTV900, RTV1100

K008-3, KX41-3, KX71-3, KX91-3S, KX121-3S, KX161-3S, KX080-3

U15, U25S, U35S, U45S, R420S, R520S

Fairbanks Morse Engine

Press Release February 1, 2007 – Fairbanks Morse Engine Approves 100% Biodiesel for use in Medium Speed Diesel Engines (Excerpt)

Beloit, Wisconsin, February 1, 2007 – Fairbanks Morse Engine, an EnPro Industries company, announced today the approval to utilize up to B100 (100% bio-diesel) in its Opposed Piston (OP) Model 38D 8 1/8 diesel and dual fuel engines for continuous operations. "Our extensive tests have demonstrated that utilizing B100 fuels that comply with the ASTM D6751 testing and specification had little impact on fuel consumption and power ratings, and had positive impacts on emissions by substantially lowering particulate matter (PM) and CO values", said Joe Eves, engineering manager – OP and FM/ALCO engines.

Bio-fuel usage in medium speed reciprocating engines is nothing new to Fairbanks Morse Engine. Experience ranges from Dutch Harbor, Alaska where UniSea, Inc. utilizes up to 100% fish oil to power six Fairbanks Morse 2.3 MW generator engines to a Dupage County, IL cogeneration facility where digester gas is burned in a Fairbanks Morse 1.5 MW generator engine. In addition, San Francisco State University has been utilizing up to B80 since the late 1990's. Recently, Fairbanks Morse Engine concluded another successful test utilizing B100 (soy-diesel) in a continuous application in Story City, IA.

Engine Manufacturers Association

Technical Statement on the Use of Biodiesel Fuel in Compression Ignition Engines
February 2007 (Excerpt)

Biodiesel Blends

A consortium of diesel injection equipment manufacturers ("FIE Manufacturers") issued a position statement concluding that blends greater than B5 can cause reduced product service life and injection equipment failures. According to the FIE Manufacturers' Position Statement, even if the B100 used in a blend meets one or more specifications, "the enhanced care and attention required to

maintain the fuels in vehicle tanks may make for a high risk of non-compliance to the standard during use." As a result, the FIE Manufacturers disclaim responsibility for any failures attributable to operating their products with fuels for which the products were not designed.

Based on current understanding of biodiesel fuels and blending with petroleum-based diesel fuel, EMA members expect that blends up to a maximum of B5 should not cause engine or fuel system problems, provided the B100 used in the blend meets the requirements of ASTM D 6751, DIN 51606, or EN 14214. If blends exceeding B5 are desired, vehicle owners and operators should consult their engine manufacturer regarding the implications of using such fuel.

Warranties

Engine manufacturers are legally required to provide an emissions warranty on their products (which are certified on EPA's diesel fuel specification) and, typically, also provide commercial warranties. Individual engine manufacturers determine what implications, if any, the use of biodiesel fuel has on the manufacturers' commercial warranties. It is unclear what implications the use of biodiesel fuel has on emissions warranty, in-use liability, anti-tampering provisions, and the like. As noted above, however, more information is needed on the impacts of long-term use of biodiesel on engine operations.

Conclusions

- Depending on the biomass feedstock and the process used to produce the fuel, B100 fuels should meet the requirements of either ASTM D 6751 or an approved European specification.
- Biodiesel blends up to a maximum of B5 should not cause engine or fuel system problems, provided the B100 used in the blend meets the requirements of ASTM D 6751, DIN 51606, or EN 14214. Engine manufacturers should be consulted if higher percentage blends are desired.
- Biodiesel blends may require additives to improve storage stability and allow use in a wide range of temperatures. In addition, the conditions of seals, hoses, gaskets, and wire coatings should be monitored regularly when biodiesel fuels are used.
- Although the actual loss will vary depending on the percentage of biodiesel blended in the fuel, the net effect of using B100 fuel is a loss of approximately 5-7% in maximum power output.
- Neat biodiesel and biodiesel blends reduce particulate, HC and CO emissions and increase NOx emissions compared with petroleum-based diesel fuel used in an unmodified diesel engine. Neither B100 nor biodiesel blends should be used as a means to improve air quality in ozone non-attainment areas.
- Biodiesel fuels have generally been found to be nontoxic and are biodegradable, which may promote their use in applications where biodegradability is desired.
- Individual engine manufacturers determine what implications, if any, the use of biodiesel fuel has on manufacturers' commercial warranties.
- Although several factors affect the cost of biodiesel fuel, its average cost exceeds that of petroleum-based diesel fuel. The relative cost of converting an existing fleet to biodiesel blends, however, is much lower than the cost of converting to other alternative fuel.

For information on Diesel Fuel Injection Equipment see: "Diesel Fuel Injection Equipment Manufacturers Common Position Statement on Fatty Acid Methyl Ester Fuels As a Replacement or Extender for Diesel Fuels" (June 2004).

Appendix B: Additional Information Sources

There are numerous sources of information on diesel fuel and biodiesel. A great deal of this information is available free of charge. In some cases, such as reference manuals or technical papers, there may be a charge. This section lists sources that proved helpful in preparing this manual. Where a charge is involved, a dollar sign ($) will appear; otherwise, the information is free of charge.

ASTM International Web site: www.astm.org (Publication orders: Phone 610-832-9585)	$ Specifications and test procedures
SAE International Web site: www.sae.org Phone: 877-606-7323	$ Reference manuals and technical papers; also *Bosch Automotive Handbook (6th Edition)*
Chevron Products Company Web site: www.chevron.com	*Technical Review – Diesel Fuels*
American Petroleum Institute (API) Web site: www.api.org	Various information papers on diesel fuels and biodiesel
National Biodiesel Board Web site: www.biodiesel.org	Various information on biodiesel
BQ-9000 Information Web site: www.bq-9000.org	Information on BQ-9000 Program
U.S. Department of Energy Web site: www.osti.gov/bridge	*Biodiesel Handling & Use Guidelines* (free if downloaded electronically)
ENG-TEK: Diesel Performance Center Web site: www.eng-tek.com.au	Various engine/systems information
National Institute for Automotive Service Excellence (ASE) Web site: www.asecert.org	Diesel technician certification tests
Bosch Web site: www.bosch.com	Fuel systems and exhaust after-treatment information
U.S. Environmental Protection Agency (EPA) Web site: www.epa.gov	Diesel engine and fuel regulations
California Air Resources Board (CARB) Web site: www.arb.ca.gov	California diesel engine and fuel regulations
National Renewable Energy Laboratory (NREL) Web site: www.nrel.gov	Various information on biodiesel and other alternative fuels
Engine Manufacturers Association (EMA) Web site: www.enginemanufacturers.org	Position statements on diesel and biodiesel
Alliance of Automobile Manufacturers Web site: www.autoalliance.org	Position statements on diesel and biodiesel; also Worldwide Fuels Charter

Appendix C: Commonly Used Acronyms

API	American Petroleum Institute
BTL	Biomass to liquids
Btu	British thermal unit
Btu/gal.	British thermal units per gallon
B2	Biodiesel blend containing 2 percent biodiesel
B5	Biodiesel blend containing 5 percent biodiesel
B20	Biodiesel blend containing 20 percent biodiesel
B100	100 percent biodiesel
CARB	California Air Resources Board
CFPP	Cold filter plugging point
CFR	Cooperative Fuel Research
CO	Carbon monoxide
CO_2	Carbon dioxide
°C	Degrees Celsius (centigrade)
°F	Degrees Fahrenheit
DI	Direct injection
DPF	Diesel Particulate Filter
ECM	Engine control module
ECU	Electronic control unit
EGR	Exhaust gas recirculation
EMA	Engine Manufacturers Association
EPA	U.S. Environmental Protection Agency
FAME	Fatty acid methyl ester
FIE	Fuel injection equipment
g/bhp-hr	Grams per brake horsepower per hour
GTL	Gas to liquids
GVW	Gross vehicle weight
HC	Hydrocarbons
HFRR	High frequency reciprocating rig
hp	Horsepower
hrs	Hours
IDI	Indirect injection
J/kg	Joules per kilogram
J/L	Joules per liter
Kg/kw-h	Kilograms per kilowatt hour
KOH	Potassium Hydroxide
Lb/bhp-h	Pounds per brake horsepower per hour
Lb-ft	Pound foot
LTFT	Low temperature flow test
NBB	National Biodiesel Board
NBAP	National Biodiesel Accreditation Program
NCWM	National Conference on Weights & Measures
NIST	National Institute of Standards & Technology
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
OBD	On-board diagnostics
OHV	Overhead valve
OTC	Over-the-counter
PM	Particulate matter
PME	Palm Methyl Ester
ppm	Parts per million
psi	Pounds per square inch
RME	Rapeseed Methyl Ester
SCC	Storage catalytic converter
SCR	Selective catalytic reduction
SLBOCLE	Scuffing load ball-on cylinder lubricity evaluator
SME	Soy Methyl Ester
SO_2	Sulfur dioxide
T_{90}	Temperature at which 90 percent of fuel will evaporate
TDC	Top dead center
ULSD	Ultra-low sulfur diesel
VGT	Variable Geometry Turbocharger

Appendix D: Conversion Formulas

Conversion of	Formula
bar to psi	# bar x 14.5038 = psi
psi to bar	# psi ÷ 14.5038 = bar
°C to °F	(# °C x 1.8) + 32 = ºF
°F To °C	(# °F – 32) ÷ 1.8 = ºC

Notes

Changes in Diesel Fuel **was prepared specifically to provide information on diesel fuel and diesel fuel quality to the diesel service and repair industry. It is based on dozens of references and was reviewed by a technical review panel to ensure accuracy.**

Changes in Diesel Fuel is available in hard copy and will soon be available for download on the Internet.

To obtain a free copy of *Changes in Diesel Fuel* or information on how to download a free electronic copy, email your request to: PetroDieselFuel@yahoo.com.

Author and Technical Review Panel

Robert E. Reynolds – Principal Author
President
Downstream Alternatives, Inc.
South Bend, IN

Allen Kasperson
Consultant
Watertown, SD
(Former coordinator for Toyota Technical Education Network, GM Satellite Training - Lake Area Technical Institute, and Co-Founder of DK Diesel Injection, Inc.)

Gary Herwick
President
Transportation Fuels Consulting, Inc.
Milford, MI
(Formerly with General Motors Corporation)

Albert M. Hochhauser
Consultant
Edison, NJ
(Former Senior Engineering Advisor, Exxon Mobil Research and Engineering Company)

Robert L. McCormick
Principal Engineer
Center for Transportation Technologies and Systems
National Renewable Energy Laboratory
Golden, CO

Carlton Jewitt
Fuels Technology Consultant
Jewitt and Associates, LLC
North Ft. Myers, FL
(Formerly with Ashland Petroleum)