A key, and often overlooked, component in the world of reliable diesel engines is the stuff that actually makes the engines run. Along with a good supply of cool air, diesel fuel is an important component of the total diesel propulsion equation.

Back in 1876, in Pico Canyon, California, primitive stills were used to boil crude oil at a prodigious rate of 25–40 barrels a day. By way of comparison, in the U.S. today we consume approximately 18.8 million barrels of oil daily.

Despite this enormous increase in production and use, distillate oil is still the same complex, organic compound it was back in 1876. Active compounds, distillate fuels are still subject to aging, degradation, and contamination. So despite the technological advances in engine and application technology, diesel fuel remains one of the weak links in overall system reliability.

Just what is diesel fuel, and where does it come from?

The Refining Process

A refinery is a factory. Just as a paper mill turns lumber into legal pads or a glassworks turns silica into stemware, a refinery takes a raw material, in this case crude oil, and transforms it into gasoline, diesel fuel oil, and hundreds of other products.

A modern refinery costs billions of dollars to build, and millions more to maintain and upgrade regularly. Such a facility runs around the clock, 365 days a year, employs between 1,000 and 2,000 people, and occupies as much land as several hundred football fields.

Essentially, the refining process breaks crude oil down into its various components, which are then selectively reconfigured into new products.

This process takes place inside a maze of hardware that one observer has likened to “a metal spaghetti factory.” Refinery operations are regulated from within highly-automated control rooms, and, because so much activity happens out of sight, refineries are surprisingly quiet places. The dominant sound is the steady, low hum of pumps.

Generally, the more sophisticated a refinery, the better its ability to upgrade crude oil into high-value products. But whether simple or complex, all refineries perform three basic steps in the crude oil distillation process: separation, conversion and treatment.

Separation: Heavy On The Bottom, Light On The Top

Not terribly different from the early “cooking” methods, modern separation involves piping oil through hot furnaces. The resulting liquids and vapors are discharged into distillation towers, tall, narrow columns that give refineries their distinctive skylines.

Inside these towers, the liquids and vapors separate into components or fractions according to weight and boiling point. The lightest fractions, including gasoline and liquid petroleum gas (LPG), vaporize and rise to the top of the tower, where they condense back to liquids.

Medium-weight liquids, including kerosene and diesel oil distillates, stay in the middle of the tower. The heavier liquids, called “gas oils,” separate lower down. There, the crude oil’s heaviest fractions (with the highest boiling points) settle at the bottom of the tower. These tar-like fractions, called residuum, are literally the “bottom of the barrel.”

The fractions are then piped to the next station or plant within the refinery. Some components, such as jet fuel or asphalt base, require relatively little additional processing, but most components destined to become high-value products require much more processing.
Conversion: Cracking And Rearranging Molecules

This is where refining’s fanciest footwork takes place—where fractions from the distillation towers are transformed into streams (intermediate components) that eventually become finished products. This is also where a refinery makes its money, because the conversion process yields valuable products that can be sold. Gasoline is one of them.

The most widely-used conversion method is called “cracking” because it uses heat and pressure to crack heavy hydrocarbon molecules into lighter ones. A cracking unit consists of one or more tall, thick-walled, bullet-shaped reactors and a network of furnaces, heat exchangers, and other vessels.

Fluid catalytic cracking, or “cat cracking,” is the basic gasoline-making process. Using intense heat (about 1,000 degrees Fahrenheit), low pressure, and a powdered catalyst (a substance that accelerates chemical reactions), the cat cracker can convert most relatively heavy fractions into smaller gasoline molecules.

Hydrocracking applies the same principles, but uses a different catalyst, slightly lower temperatures, much greater pressure, and hydrogen to obtain its own chemical reactions.

Some refineries also have cokers, which use heat and moderate pressure to turn residuum into lighter products, as well as a hard, coal-like substance that is used as an industrial fuel.

Cracking and coking are not the only forms of conversion. Instead of splitting molecules, other refinery processes rearrange them to make other valuable products.

Alkylation, for example, makes gasoline components by combining some of the gaseous byproducts of cracking. The Alkylation process, which is essentially cracking in reverse, takes place in a series of large, horizontal vessels and tall, skinny towers that loom above other refinery structures.

Reforming uses heat, moderate pressure, and catalysts to turn naphtha, a light, relatively low-value fraction, into high-octane gasoline components.

Treatment: The Finishing Touch

Back in the early days of “oil boiling,” companies didn’t have to worry about customer or government standards. But today, a major portion of refining involves blending, purifying, fine-tuning, and otherwise improving products to meet these often stringent requirements.

Diesel Fuel Specifications

The diesel fuels available for purchase in the marine marketplace must also meet certain minimum specifications.

In the U.S., the standard specification for diesel fuel oils is ASTM D 975. (ASTM stands for the American Society of Testing and Materials). ASTM D 975 contains a set of physical, chemical, and performance specifications, established by the Society to meet the approval requirements of ASTM procedures and regulations.

The ASTM is not a regulatory or enforcement agency, but their standards have been adopted by several government agencies. It is also one of the largest voluntary standards development systems in the world. ASTM’s standards encompass metals, paints, plastics, textiles, petroleum, construction, energy, the environment, consumer products, medical services, computerized systems, electronics, and many other areas.

Fuel Properties (What The Specs Mean)

Compression-ignition (diesel cycle) engines run on middle-distillate fuels, with boiling ranges higher than those of gasoline, but lower than that of lubricating oil base stocks. The best diesel fuels are “straight-run” stocks, derived from simple distillation of crude oil.

But many commercial fuels contain a proportion of catalytically-cracked material to extend the yield.

The important properties of diesel fuels are volatility, heating value, ignition quality/cetane number, viscosity, low-temperature flow, lubricity, storage stability, component compatibility, and sulfur content. Let’s look at these properties.

What's in a Barrel of Crude Oil?

Output varies with crude selection, but the average breakdown is as follows:

<table>
<thead>
<tr>
<th>Product</th>
<th>Gallons per barrel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>19.5</td>
</tr>
<tr>
<td>Distillate fuel oil (includes home heating and diesel fuel)</td>
<td>9.2</td>
</tr>
<tr>
<td>Kerosene-type jet fuel</td>
<td>4.1</td>
</tr>
<tr>
<td>Residual Fuel Oil</td>
<td>2.3</td>
</tr>
<tr>
<td>(Heavy oils used in industry, marine transportation, and power utilities)</td>
<td></td>
</tr>
<tr>
<td>Liquefied refinery gases</td>
<td>1.9</td>
</tr>
<tr>
<td>Still Gas</td>
<td>1.9</td>
</tr>
<tr>
<td>Coke</td>
<td>1.8</td>
</tr>
<tr>
<td>Asphalt &amp; road oil</td>
<td>1.3</td>
</tr>
<tr>
<td>Petrochemical feedstocks</td>
<td>1.2</td>
</tr>
<tr>
<td>Lubricants</td>
<td>0.5</td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.2</td>
</tr>
<tr>
<td>Other</td>
<td>0.2</td>
</tr>
</tbody>
</table>

In the oil business, a “barrel” is a unit of measure that is equal to 42 gallons, as opposed to the 55 gallon steel drums with which most of us are familiar.

(If you’ve added up the numbers, you found that the sum came to 44.2 gallons, of which the 2.2 extra gallons represent “processing gains.”)
Volatility: The volatility of a diesel fuel has little influence on its engine performance, except as it affects exhaust smoking tendencies. The distillation range of a diesel fuel does not allow much flexibility in this regard, because of the interdependence with other specification factors. Because diesel fuels are classified as nonflammable for freight purposes, minimum flash point restrictions are imposed.

Heating Value: Generator operators, fleet operators, railroad and shipping companies are concerned about kW output, and fuel economy. They aim to use the fuel with the greatest heating value. The factors that influence heating value are density and mid-boiling point.

Ignition Quality/Cetane Number: This factor influences ease of starting, duration of white smoking after start-up, driveability before warm-up, and intensity of diesel knock at idle. Recent studies have correlated ignition quality with all regulated emissions. As ignition delay is reduced, the combustion process starts earlier, and emissions are reduced.

Ignition delay is measured by the Cetane Number test (ASTM D 613), which uses a single-cylinder, variable-compression ratio engine, analogous to the Octane Number engine. The factor measured is ignition delay (rather than knock) at a fixed compression ratio, which is then compared with the delay from standard reference fuels (consisting of blends of n-cetane and heptamethylnonane). The cetane content of the blend that most closely matches the ignition delay of the test fuel is its Cetane Number (CN).

Diesel engines vary widely in their cetane requirements, and there is no commonly recognized way to measure this value. In general, the lower a diesel engine’s operating speed, the lower the CN of the fuel it can use. Large marine engines can tolerate fuels with CNs as low as 20, while some manufacturers of high-speed passenger car diesel engines specify 55 CN fuel. Canadian railroads now purchase fuel to a 37 CN minimum specification, and most diesel genset manufacturers call for a 40 or 45 minimum.

Some Facts About Oil:

- Total remaining recoverable U.S. oil may exceed 200 billion barrels—or about a 70-year supply at current consumption. Total world reserves may exceed 2 trillion barrels.
- Adjusted for inflation, the average cost of motor gasoline to consumers is at its lowest level in 77 years, thanks to lower crude costs and improved industry technology.
- About half of the oil Americans consume is produced here in the U.S.; the rest is imported. Of that, about 51% is imported from other nations in the Western Hemisphere, 21% from the Middle East, 18% from Africa, and 11% from other countries.
- It takes about 20 new cars today to produce the tailpipe pollution of one new car made in 1960, as result of cleaner burning gasolines and improved automobile technology.
- The U.S. oil and natural gas industries spent nearly $10 billion on environmental protection in 1995; that’s almost nine cents for each gallon of gasoline sold.
Cetane Number (but not Cetane Index) can be increased by using cetane improvers. These additives, usually organic nitrates, boost CN by 2 to 7 numbers, depending on the dosage and type of base stock used.

**Viscosity:** Viscosity influences the spray pattern when the fuel is injected into the cylinder. Low-speed marine engines can use higher-viscosity fuels than high-speed road-transport and generator engines, and still run without excessive smoking. Minimum viscosity limits are imposed to prevent the fuel from causing wear in the fuel injection pump.

**Low-Temperature Flow:** Unlike gasolines, which have freezing points well below even the most severe winter ambient, diesel fuels have pour points and cloud points well within the range of temperatures at which they might be used. This can be of particular concern when using fuel delivered during the summer season. Prior to the onset of cold weather, it might be a good idea to test the fuel for suitability.

Seasonal blending to control cloud point (the temperature at which a cloud or haze of wax crystals first appears and separates from the fuel) is the refiner’s assurance against field problems.

Because it is not practical to specify low temperature properties that will ensure satisfactory operation at all ambient conditions, ASTM has developed geographic guidelines instead of a single temperature specification.

In the winter, there is also an increasing tendency to use flow improvers, as well as polymeric additives that modify the wax structure as it builds up during cooling. These additives keep wax crystals small, so they can pass through the fine pores of fuel filters, enroute to the injector pump.

**Storage Stability:** All diesel fuels—even the cleanest—oxidize in the presence of air, heat, and water, particularly if the fuel contains cracked products which are relatively unstable. Most diesel fuels today contain cracked products—primarily light cycle oils and olefinic components (unsaturated hydrocarbons). The typical percentage of these components in diesel fuel is about 12 percent.

While standards for stability are not widely adopted, fuel stability is gaining recognition within the ASTM and some engine builders. Fuel stability is important because unstable components can cause filter plugging, combustion chamber deposits, and the gumming and lacquering of injection system components. The result is reduced engine performance, greater engine wear and reduced fuel economy.

**Engine Component Compatibility:** Diesel fuels are injected into the engine through precision pumps and fine injector nozzles. Dirt and water contamination must be avoided to protect these critical components. Specifications include tight limits on water and sediment, and most fuel stations also install final filters at the nozzles of fuel dock

Diesel fuel really is a simple, yet complex, product—whose performance and reliability are often taken for granted.

service pumps to protect against dirt picked up in the distribution system.

**Carbon Residue:** Deposit build-up in engines is also influenced by fuel quality. Fuels that leave a heavy carbon residue and contain excessive amounts of high boiling-point materials are prone to cause engine deposits. Therefore, limits are placed on carbon residue and the distillation 90% evaporated temperature (ASTM D 86).

**Sulfur Content:** Sulfur content is the first diesel fuel property to be widely controlled by legislation, aimed at limiting exhaust emissions. Sulfur is present in all crude oils and as well as all refined products.

During combustion, however, sulfur compounds burn to form acidic byproducts, SO₂ and SO₃, which form sulfates in the exhaust gas stream. Sulfates are part of a diesel engine’s particulate emissions, therefore, controlling fuel sulfur level reduces the level of sulfate pollutants.

Depending on the crude source, sulfur compounds can also create corrosive sulfur oxides on combustion. These can cause high rates of engine wear and a rapid depletion of engine oil additives. Engine manufacturers often relate oil change intervals to the fuel sulfur content. According to Detroit Diesel, “diesel fuel sulfur content above 0.3% mass causes premature ring and cylinder liner wear and deposit formation.”

**Water Content:** Diesel fuels also contain small amounts of water. Hydrocarbon type and bulk temperature control the amount of dissolved water that a fuel holds.

As the temperature decreases, the amount of water dissolved in the fuel will also decrease, which may lead to a water layer forming on the bottom of the fuel storage tank. To prevent subsequent bacterial contamination, as well as the pumping of water into the fuel distribution system, draining the lowest level of all tanks regularly should minimize this layer.

Many diesel fuel treatments are offered to control this water content. These additives typically contain glycol or various types of alcohol (most often Isopropanol) which absorb their own weight in water (they are hydroscopic), and emulsify the water back into the fuel.

These additives are very popular, especially in the trucking and marine industry. But they carry with them a very serious risk.
Consider that water is much denser than fuel. When this encapsulated water hits a hot injector tip, it quickly expands into steam. Potentially, this can result in cracked, damaged, or blown-out fuel injectors, to name just a few of the potential problems.

The best remedy to minimize water contamination is to keep all fuel tanks “topped off.” If water exists, then it should be drained from the bottom of the tank, or the fuel processed through separation filters or centrifuges.

Summary

The U.S. petroleum industry is dedicated to producing a high quality product for the marketplace. Diesel fuel really is a simple, yet complex, product—whose performance and reliability are often taken for granted.

We depend on our trawler’s diesel engine for reliable and consistent power on a regular basis when we go cruising.

At the same time, the typical trawler carries a large fuel load, which is often stored over a long period of time. Diesel fuel remains a complex, active organic compound, and fuel quality can vary a great deal.

But with proper testing and additives, and a well-designed fuel storage and delivery system, high quality diesel fuel can easily be stored for many years. This discussion may be more than you need to know about diesel fuel. But those of us in the fuel industry take this subject very carefully—so you don’t have to.

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**Diesel Terminology**

**Additive**: A chemical added to fuel to enhance one or more of its properties.

**BTU**: British Thermal Unit, a measure of the energy content of a fuel.

**Flash Point**: the lowest temperature at which vapors from a fuel will ignite on application of a small flame under standard test conditions.

**Gelling**: A thickening of the fuel (similar to solidifying gelatin) caused by wax crystals which form as the fuel cools down. Gelled fuel is difficult to pump and can plug filters, preventing fuel from reaching the engine (fuel starvation). Often mistaken for ice in fuel, but can be identified as the fuel filter is warmed.

**High Sulfur Diesel Fuel**: Contains greater than 0.05% weight (500ppm) sulfur.

**Icing**: The formation of ice crystals in a fuel containing free water when cooled to 32°F or below. Although ice crystals will plug filters in the same manner as wax, it is important to determine which problem is occurring so as to take proper corrective action.

**Kerosene**: A class of light petroleum distillate fuels, such as those used in aviation turbine engines, certain heating appliances, and for blending winter diesel fuel. There are two different grades: 1-K is a special low sulfur kerosene suitable for non-flue-connected applications; 2-K is a high sulfur kerosene suitable for flue-connected applications. The blending of kerosene into diesel fuel to improve cold temperature performance adversely affects the BTU content of the diesel fuel.

**Low Sulfur Diesel Fuel**: Contains less than 0.05% weight (500 ppm) sulfur and meets other EPA and IRS requirements for highway use.

**Lubricity**: Lubricating-ability, is a measure of a diesel fuel’s ability to prevent wear on contacting solid surfaces found in some fuel pumps and injectors. In the case of diesel engines, some fuel pumps and fuel injectors are lubricated by the fuel. So lubricity is a measure of a diesel fuel’s ability to prevent wear in these parts.

**No. 1-D Diesel Fuel**: A lighter, kerosene-based diesel fuel having a lower viscosity, density, cloud point, pour point, and less BTUs per gallon than No. 2-D diesel fuel. It is used for extremely low temperature operation and is commonly blended with No. 2-D diesel fuel to improve No. 2-D’s cold temperature performance.

**No. 2-D Diesel Fuel**: The standard grade of diesel fuel used in heavy duty trucks, diesel cars, and marine applications. No. 2-D diesel fuel is sometimes blended with No. 1-D diesel fuel to improve No. 2-D’s cold temperature performance.
Sources
- American Petroleum Institute (API)
- Chevron Oil Company
- Detroit Diesel Corporation
- Mobil Oil Corporation
- Power Research Incorporated

For More Information
- American Petroleum Institute
  1220 L Street, NW
  Washington, DC 20005
  202-682-8000

- American Society for Testing and Materials
  100 Barr Harbor Drive
  W. Conshohocken, PA 19428
  610-832-9500

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Alex Marcus is the Chief Engineer at Environmental Solutions International, Inc. (ESI), a company that specializes in engineering technology and products to enhance the reliability of stored fuels and diesel powered equipment. He has been awarded a patent for ESI’s Clean Fuel System. A graduate of SUNY Maritime College at Fort Schuyler, New York, with a degree in Naval Architecture and Marine Engineering, his professional experience includes American Bureau of Shipping (ABS) and more than a decade with Mobil Oil in both fuels and lubricants. Alex is a member of the industry group ASTM and sits on several committees specializing in diesel fuel quality and filtration.

If you have any questions or comments regarding this article or to discuss your fuel filtration needs with a fuel management specialist, please call Environmental Solutions International, Inc. in the USA at 800-411-3284, or internationally at 703-263-7600. Email ESI at info@fuelmanagement.com.

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ESI-Clean Fuel System™ is engineered to address all aspects of maintaining high quality fuel for peak performance and reliability of your diesel engine. Don’t let contaminated fuel jeopardize your safety when cruising.

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