Driving Home the Impact of Diesel Fuel Properties

In this third in a three-part series, Roger L. Leinsenring, Jr., discusses how certain diesel fuel properties will keep an engine clean and running.

What do you know and who do you trust?
This is the third of three articles by Roger Leisenring on the evolving story of diesel fuel. The first article (“The Changing Face of Diesel Fuel Today,” February 1999, page 10) set the stage for understanding the concerns that have led to extensive debate on the composition of both regular and premium diesel, which was the subject of the second article (“Premium Diesel Fuel: Why the Controversy?” March 1999, page 12). In this third article, Leisenring examines diesel fuel and additive properties and explains their performance benefits.
I don’t think there is any argument that the diesel engine has long been the workhorse of the transportation industry. Diesel makes this country run. It is chosen not just for its fuel economy and power, but also for its durability and reliability.

However, as I mentioned in the February and March issues, the diesel engine’s reliability, durability and performance can be affected by the fuel quality. The quality of the fuel and engine performance may be enhanced if the fuel properties exceed today’s minimum standard for diesel fuel (ASTM D 975). Therefore, it is prudent at times to purchase diesel fuels that exceed the minimum specifications; however, you need to be aware of what you’re getting, as well as what you’re not getting. Also, you need to know whether your individual needs call for fuel that exceeds the minimum specifications.

In my February article in PE&T, I described how fuels were manufactured and the meaning of diesel fuel specifications. In the March issue, we focused on premium diesel fuel. This article will concentrate on some of the fuel properties that have a direct impact on the operation of your diesel engine.

Low temperature operability
The winter season is finally behind us; and for much of the country, it was on the mild side. However, the need remains for reliable information on the low temperature operability of diesel fuel. Otherwise, the usual penalty is a call for a tow truck along the interstate.

Proper attention to diesel fuel’s low temperature properties is essential for any diesel-powered vehicle or equipment operator. For operating in air temperatures above 20 degrees F, most diesel engine builders recommend ASTM D 975 Grade No. 2-D diesel fuel.

At extremely low temperatures, the diesel engine builders recommend No. 1-D diesel (kerosene), which usually has a lower cloud point and a lower pour point than No. 2-D. Cloud point is the temperature at which a haze or cloud of wax crystals first appears in the fuel when it is cooled under standard testing conditions. Pour point is the lowest temperature at which a sample of diesel fuel will flow when cooled under standard testing conditions.

Between very low temperatures, such as -15 and 20 degrees F, the use of a “winterized” No. 2-D diesel is recommended. This is a No. 2-D that has been modified to permit its use at lower air temperatures. The most common way to winterize a fuel is by blending No. 1-D with No. 2-D, but additives can also be used.

The final No. 1-D/No. 2-D blend will start to gel at a lower temperature because of a lower cloud point. It is this lower cloud point, rather than pour point, that improves the low temperature operability of the final fuel blend. Pour point, on the other hand, is routinely used for quality control and to provide an indication of the diesel’s storage and handling limits. Pour point has often been used as an indicator of a diesel fuel’s low temperature vehicle operability, but this is a poor indicator because it is neither reliable nor predictable.

The gelling phenomenon

At low temperatures, wax crystals can start to form in diesel fuel. The fuel starts to look hazy—not the pristine clear that we are all used to. In the vehicle’s fuel system, these wax crystals can collect on the fuel filters and cause them to plug. The photo below is a filter with wax buildup, which clearly demonstrates the hazards of using fuels that are not winterized.

This phenomenon can result in engine stumbling or stalling. The temperature at which this occurs is usually identified as the low temperature operability limit of the fuel and vehicle. Both vehicle-fuel system design and fuel properties are important factors in determining the minimum temperature for acceptable vehicle operation.

While winterizing No. 2-D fuel by adding No. 1-D improves low temperature performance, there are economic and performance penalties associated with this practice. The reason is that No. 1-D diesel (kerosene) has an energy content (heat of combustion) less than that of No. 2-D. The energy content of diesel fuel is the amount of energy stored in a gallon. Measured in British thermal units (Btu) per gallon, diesel fuel’s energy content is related to the hydrocarbon mixture in the fuel.

The terms “gross” and “net” are used in conjunction with the term, “heat of combustion.” The gross heating value includes the latent heat of water from combustion that condenses in the test procedure. In an engine, the water is exhausted in the form of a vapor. So, it is the “net” heat of combustion that is important.

In some engines, diesel fuel with a higher energy content can provide higher power and improved fuel economy. And likewise, a diesel fuel with less energy will provide less power and reduced fuel economy. This is very pertinent during the winter season because of “winter blending,” which was discussed earlier. Since winter blending involves blending No. 1-D (a lower gelling fuel) with No. 2-D, the resulting fuel blend typically has a lower overall Btu content compared to a straight, unwinterized No. 2-D. This lower Btu content has a detrimental effect on fuel economy and is directly proportional to the amount of No. 1-D used in the winter blend.

As Figure 1 shows, it is possible for the fuel economy penalties to be as high as 8.7 percent as various amounts of No. 1-D are blended into No. 2-D. Blending No. 1-D into No. 2-D has the same negative effect on engine power; that is, the power can be reduced by as much as 9.2 percent as various amounts of No. 1-D are blended into No. 2-D. **(See Figure 2.)** Simply, No. 1-D (kerosene) can be more costly than No. 2-D. This extra cost and the loss of fuel economy, as discussed above, can significantly raise the cost of operating a vehicle. **Figure 3** combines the cost penalty for reduced fuel economy and the additional cost for No. 1-D fuel.

Is there a better way, please?

Yes, additive treatment is an alternative for improving the low temperature operability of diesel fuel. Additives used for this purpose change the size and shape of the wax crystals that form as the diesel fuel is cooled below its cloud point.

Keep in mind that wax crystals still form on the filter. However, now the wax crystals have been altered and modified, which allows fuel to pass through the wax and the filter into the engine. In other words, without additives you have a solid block of wax on the filter. With additives, this block of wax now has microscopic passageways for the fuel to continue to flow.

Numerous concerns surround the use of winter diesel fuel additives. The chemistry of the different additives used for this purpose varies. Further, not all diesel fuel performance additives are compatible with low temperature operability additives. In fact, some additives can actually negate the benefits of others, resulting in poorer handling and vehicle performance. So, the amount and quality of “no harm” testing by the additive supplier is an important factor when selecting an additive.

How will you know if the additives work? The obvious answer would be, if your vehicle stops working, so did the additive. As ridiculous as this may sound, it happens. Therefore, a consumer needs to know how an additive’s properties have been measured and its benefits substantiated. However, for many consumers, these facts may prove very difficult to get. Fleet managers who purchase additives in bulk may have better luck in obtaining this information, because they sometimes deal directly with a sales person who is familiar with the product.

The fuel and additive industries have two test methods available for the evaluation of the low temperature operability of diesel fuel treated with additives: the Cold Filter Plugging Point test (CFPP); and the Low Temperature Flow Test (LTFT). Both bench test methods attempt to predict a minimum temperature at which the vehicle will have an acceptable performance.

The CFPP test has been used in Europe for many years with success and is a quick-cool test. That is, a fuel sample is placed in a controlled temperature bath and is rapidly cooled (by 40 degrees C per hour). The CFPP test temperature is the temperature of the sample when 20 ml. of the fuel first fails to pass through a wire mesh in less than 60 seconds.

The LTFT was developed in North America. In contrast to CFPP testing, LTFT is a slow-cooled test. The fuel sample is cooled at a rate of one degree C per hour. The slower cooling rate was chosen to mimic as closely as possible the behavior of the fuel exposed to overnight temperatures.

In some vehicle and engine configurations, LTFT has been shown to have a better correlation with field tests compared to that of CFPP testing—but not in all cases. In fact, CFPP testing has been shown to correlate quite well with some vehicles. Also, because of the extremely slow cooling rate that requires 12 to 24 hours to complete, the LTFT method is very impractical for routine fuel testing.

So, if you are able to acquire CFPP or LTFT results, scrutinize them. Do they sound believable? If you are in doubt, look for a supplier who conforms to the National Council on Weights and Measures (NCWM) premium diesel fuel requirements since there is a low temperature operability specification. The chances are very good that you will get the low temperature performance that is promised from such a supplier. This is because NCWM spent quite a bit of time reviewing data before making the low temperature recommendation as part of the NCWM definition of premium diesel.

Fuel injector cleanliness

Today, fuel injectors make the engine run at peak performance. There is no disagreement that trucks and engines built today are lasting longer. It is not unusual for a big block engine in a highway tractor to have 700,000, 800,000 or even 900,000 miles before an overhaul is needed. It is also not unusual to pay $100,000 or more for a new truck.

Fuel injectors **(Figures 4 and 5)** are the heart of the diesel engine. They are high-precision components designed to meter fuel to a very high degree of accuracy. The correct behavior of the engine depends on the injector doing its job properly; otherwise, there will be repercussions in terms of noise, smoke, emissions and performance.

Proper functioning of the injectors is essential for peak performance; therefore, it is beneficial to keep the nozzles operating at their peak performance as much as possible. Any buildup of carbon on the injector, as shown in Figure 5, has the potential to disrupt the spray pattern of the fuel being injected into the cylinder. This can lead to incomplete combustion, which can cause increased black smoke, decreased power or poor fuel economy.

Effect of injector fouling

The tip of the fuel injector is subject to a very harsh environment. This tip is in direct contact with the combustion process, both in direct and pre-chamber (indirect) injection engines, as shown in **Figures 6 and 7** on the next page. The solid-matter products of combustion are deposited on the tip, and can alter significantly the operation of the injector.

For pre-chamber engines, the combustion products partially block the progressive delivery of the fuel during the various load requirements of the engine, and the combustion can become violent and disorganized. Likewise, in direct injection engines, a partial or complete blockage of one of the fine spray holes will disrupt the atomization of the fuel spray, and the engine will no longer function as designed.

With pre-chamber engines, coking is inevitable due to the type of injectors used. Coking refers to carbon-type deposits that remain after exposure to the hot combustion gases. However, the amount of coking on the injector tip and in spray holes depends on the quality of the diesel fuel. Keep in mind that excessive coking cannot be tolerated if you expect to maintain your engine at peak performance.

Solution:
The solution to injector fouling is to use a detergent additive. High doses of an additive can clean an already-coked nozzle, while smaller doses can maintain a “keep clean” state of operation. The ability of an injector to keep clean will become more important in the future as emission regulations, performance requirements and customer expectations put tremendous pressure on engine manufacturers to squeeze every bit of performance out of the engine.

Detergent additives to control fuel-injection nozzle deposits became an important part of a premium diesel fuel when the Engine Manufacturers Association endorsed a detergent requirement in its FQP-1A document. The test method, L-10 Injector Depositing Test, was developed by Cummins to evaluate fuel and fuel additive effectiveness in reducing fuel deposits on direct-injection nozzles typically found in heavy-duty engines.

The test utilizes a Cummins 1988 turbocharged L-10 engine with Pressure Time (PT) injectors. The engine is cycled at 15-second intervals between closed rack and partial rack for a total of 125 hours. At the conclusion of the test, the fuel injectors are removed and flowed for determining the percent of fuel flow loss. In addition, the plungers in the injector bodies are removed and visually rated for the amount of deposit using the Coordinated Research Council (CRC) rating scale. Typically, a “dirty” fuel, unadditized, will have CRC ratings over 20 and an additized fuel will have CRC ratings of less than 10.

Cetane
Cetane number is one of the most widely-known parameters of diesel fuel. However, awareness doesn’t always mean understanding, and there is a danger that cetane number can be confused with cetane index. So, a brief explanation is in order.

A diesel engine is a compression ignition engine. That is, the diesel fuel is ignited by the high-temperature, high-pressure air that is created in the cylinder as the piston nears the end of the compression stroke. By comparison, fuel in gasoline engines is ignited by a spark plug. The cetane number is a measure of the ease with which diesel fuel is ignited during the compression stroke of the diesel engine.

The cetane number for a given fuel is determined by using a specified laboratory diesel engine to test the fuel. The cetane index, on the other hand, is the result of a calculation using an equation involving, as variables, the API gravity (density) and the distillation curve of the diesel fuel.

Consequently, the cetane index cannot be increased and improved by cetane-improving additives because the equation does not take into account the amount of cetane-improving additive added to the fuel. Therefore, if there is no place to put the amount of cetane-improving additive into the equation, there is no way of changing the cetane index except by changing the API gravity and/or the distillation of the fuel.

When injected into the combustion chamber of the cylinder, the fuel must quickly mix with air and then ignite, without any other ignition source. The time between the beginning of fuel injection and the start of combustion is called “ignition delay.”

Higher cetane number fuels result in shorter ignition delay. This shorter ignition delay results in improved combustion, lower combustion noise, easier cold starting, faster warm-up, reduced white smoke and, in many engines, reduction of some regulated emissions. In addition, several Society of Automotive Engineers technical publications have reported better fuel economy and increased power as a result of increasing the cetane number with additives.

Additionally, Texaco Additive International’s R&D Department’s research demonstrated that an average 4.6 percent decrease in power, with an average 4.2 percent increase in fuel consumption, resulted when a diesel engine was run with naturally high-cetane fuel instead of the naturally low-cetane fuel improved to the same cetane number with additives.

The disadvantage of using a naturally occurring high-cetane fuel compared to an “additive-improved” cetane fuel is that the former are, in general, less dense. This lower density, the same as a winterized fuel, has lower volumetric energy content, so fuel economy and power available per volume of fuel injected into the engine is reduced. Since fuel is bought on a volumetric basis, this represents a direct economic loss to the customer.

The NCWM Task Force analyzed data for a set of 300+ diesel fuel samples. The average cetane number for this group of fuels was approximately 44. This seems representative of the national average for all diesel fuels. The engine performance data available to the NCWM Task Force indicated that an incremental increase of three points in the cetane number above the average (which would also be an increase of seven points above the minimum ASTM specification of 40) will provide an added performance benefit in some engines.

The Engine Manufacturers Association, the American Trucking Association, the American Automobile Manufacturers Association and the recently-announced automotive manufacturers, the World-Wide Fuel Charter, all stress that the cetane number for premium diesel should be well above the national average. These organizations have stated that diesel engines will operate better on fuels with cetane numbers above 50.

Lubricity

There is little doubt, if any, that diesel fuels with inadequate lubricity will cause accelerated wear in fuel-lubricated rotary fuel injection pumps. Increased wear in the injection pump can lead to increased tailpipe emissions, premature equipment overhaul, poor fuel economy, less power and catastrophic pump failure in some cases.

This is extremely disheartening when you consider the amount of money that fleets, municipalities and the public spend on diesel fuel. There is no exception; diesel fuel must provide adequate lubricity to fuel injection systems.

Two tests to determine fuel lubricity values:

Figure 8: SLBOCLE ASTM D 6078

Figure 9: HFRR ASTM D 6079

Tests have shown that fuels with sufficient lubricity protect fuel injection pumps. Currently, two ASTM Standard Test Methods are available for determining fuel lubricity values: ASTM D 6078 (Scuffing Load Ball On Cylinder Lubricity Evaluator) and D 6079 (High Frequency Reciprocating Rig). However, lubricity is not being recommended for inclusion in the NCWM premium diesel fuel regulation at this time for several reasons. The test methods currently have large reproducibility and repeatability limits, making enforcement questionable. Therefore, while the NCWM Premium Diesel work group recognizes the performance value of adequate lubricity, it recommends excluding lubricity parameters from premium diesel’s definition, pending further research and better test method development.

The two lubricity test methods are somewhat similar. The ASTM D 6078 method (Figure 8), based on the Ball On Cylinder Lubricity Evaluator (BOCLE) test (ASTM D 5001), determines the maximum load that can be applied without causing scuffing. A steel cylinder is immersed into the diesel fuel sample and rotated at a speed of 525 rpm. A hardened steel ball is placed in contact with the rotating cylinder and load is then applied.

The ASTM D 6079 method (HFRR, Figure 9) uses a hardened steel ball oscillating across a hardened steel plate under a fixed load for 75 minutes. The point of contact between the ball and plate is immersed in the diesel fuel sample. A load is applied to a steel ball as it is immersed in the diesel fuel.

With the SLBOCLE test method, the load under which scuffing wear occurs is the reported result, whereas the HFRR method measures the wear on the ball. Typically, a good lubricity fuel as measured by the SLBOCLE method will have a rating of 3,000 grams or more of load capacity. The HFRR method will result in rating these fuels at not more than 460 microns of wear. If it sounds confusing, it can be.

Just keep in mind that a high load rating under the SLBOCLE method is good, and a high wear or "scar" measurement under the HFRR method is bad.

Until ASTM or NCWM issues a specification for lubricity, the consumer is at a disadvantage. However, by knowing the two tests that are used to measure lubricity and what the levels for a good fuel should be, the consumer can interpret lubricity claims that might be made at the pump.

Stability

When stability is mentioned, most of us think of storage stability. That is, as fuel ages it can become unstable, which results in the formation of insoluble particulates that accumulate and eventually end up on the fuel filter. However, diesel fuel is increasingly being used as a coolant for high-pressure fuel injection systems, which can thermally stress the fuel. In some cases, this stress can cause the fuel to degrade and form insoluble materials as well, which can restrict fuel flow through filters and injection systems.

Quite a few test methods are used for evaluating a fuel's stability characteristics. However, only three such methods are used routinely by the fuel and additive industry: ASTM D 2274, the Octel F21-90 minute test and the Octel F21-180 minute test.

ASTM D 2274 is an accelerated oxidation stability test. Oxygen is bubbled through a diesel fuel sample for 16 hours, after which the fuel is filtered to collect any insoluble materials. Fuels that have insoluble materials of less than 15 mg/Liter are usually deemed to be stable.

Both Octel tests are thermal stability tests; the only difference between the two being the amount of time the fuel is thermally stressed. The fuel is subjected to a 302 degree F bath for either 90 or 180 minutes. Afterwards, the fuel is filtered to collect all insoluble materials and a result, as measured by light reflectance, is reported. ASTM is developing the 180-minute test into a standard test method because it has been shown to discriminate between a stable fuel and an unstable fuel better than the 90-minute test.

The pipeline companies consider a fuel with a reflectance of greater than 70 percent to be a good regular diesel fuel, whereas NCWM considers a fuel with 80 percent reflectance to be a step above a regular diesel fuel.

Bugs

Microorganisms (bugs, fungi) in diesel fuel are a constant concern for users. This is especially important in fuel facilities where diesel fuel may be stored. Microorganisms can occur in saddle tanks, but not at the same frequency as they do in other kinds of tanks. These bugs grow wherever water meets fuel. They feed at the interface, but live in the water. Bug growth can form a gel-like substance that can clog fuel lines and filters.

The best way to prevent the problem is to keep the water out of your system. This is not always the easiest way. A recent study showed that many storage tanks are tilted in the opposite direction than the owners thought they were positioned, so that water was accumulating without the owner's knowledge—a perfect breeding spot for bugs.

Once bug contamination of a fuel storage tank occurs, the cleanup can be a difficult and expensive task. For severe cases of contamination, where there is a large interfacial mass, physical removal of the bugs' debris is important. Depending on the severity of the problem, manual cleaning of the storage tank or the saddle tank may be required before refilling. This is to remove debris and corrosion (byproducts of microorganism growth) from the interior surface.

If a biocide is added to the fuel before cleaning, the increased amount of debris that occurs as the microbial mass breaks up should be taken into account. In less severe cases of contamination, where little debris is present, it may only be necessary to filter the fuel to remove the debris; however, this filtration may require frequent filter changes.

Used engine oil

For years, mixing used engine oil in with diesel fuel has been a common practice, especially among fleets. The obvious reasons are that it reduces fuel cost and is an easy way to dispose of the used engine oil. However, most engine manufactures do not recommend burning used oil in diesel fuel because any of the following may occur:increased wear of injectors, plugged filters, carbon deposits on piston tops and excessive exhaust emissions.

Burning oil with on-highway diesel fuel may also violate the federal low sulfur fuel regulations (40 CFR, Part 80). The sulfur in the oil may put the fuel over the federal limit of 0.05 percent. In addition, several states consider used oil a hazardous material and "dumping" this material in the fuel is prohibited because of their hazardous material handling laws.

Back on your own

Well, this brings to an end the three part series on diesel fuels. I hope it has helped you understand the diesel fuel issues, so that you are now an educated consumer. Although several organizations and agencies are watching the fuels industry, the ultimate responsibility for assuring that you are getting what you pay for rests with you. But dealing with a supplier who has earned your trust makes that job just a little bit easier.

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