ASSOCIATION OF EQUIPMENT MANUFACTURERS

New Diesel Fuels:
They Are In Your Future For Nonroad Equipment

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It seems that new diesel fuel types and blends have been entering the market place, well, about as long as diesel engines have been around. However, you might be reading and hearing more recently that new diesel fuels will be moving into the nonroad market. Assuming owner/operators are generally pleased with the current performance of standard No. 2 Diesel, what's the impetus for a changeover? What advantages do they bring and at what cost, and more importantly, will they run reliably in existing farm and construction equipment?

LOW SULFUR DIESEL

It's almost a sure thing that diesel fuel with lower sulfur content will gradually displace the high sulfur fuel that is in widespread use in nonroad equipment. Today's diesel fuel for nonroad use can be up to a maximum of 5000 parts per million (ppm) sulfur, but typically is found around 3500 ppm or less. On-Highway diesel fuel is required to be <500 ppm sulfur, and that fuel on average is about 350 ppm sulfur, which is ten times cleaner than most nonroad diesel used today.

It is a fact that sulfur is not particularly helpful for the life of your engine, not good for the environment, and has been identified by EPA as an air pollutant. Combustion blow-by can introduce sulfur compounds into the engine's crankcase where they combine with moisture to form sulfuric acid that accelerates the erosion of cylinder liners. The sulfur compounds are also expelled into the atmosphere with the exhaust where they contribute to acid rain. In addition, the sulfur chemically combines with oxygen in the air to form sulfates, which are fine particles that we can't see, but can be ingested deeply into our lungs.

All crude oil sources contain some amount of sulfur compounds. Sulfur is a major headache and expense for fuel refiners to remove from the finished product, and so low sulfur fuel costs more to produce than high sulfur diesel – between 1 to 3 cents more per gallon than conventional high sulfur fuel. Even so, it's been reported that 10 percent of the highway grade diesel (<500 ppm sulfur) produced is consumed in off-highway applications (e.g. farm, construction, rail & industrial). Many contractors and some farm operators, for example, choose to purchase the highway-grade diesel for convenience, to ensure the durability of their equipment and to minimize maintenance costs.

Future EPA regulations specifying more stringent exhaust emission controls being proposed for 2006 and later model nonroad diesel-powered equipment will require the use of the highway-grade of fuel (<500 ppm sulfur). It's too early to determine how EPA will ensure that adequate supplies of 500 ppm diesel fuel will be available to the new machines that require it, but EPA could rule to convert the entire nonroad diesel pool to the lower sulfur fuel.

Clearly, the impetus for fuels change is the EPA's long-term initiative to achieve environmental improvements by requiring cleaner diesel engines to be sold in the off-highway sector as they have been for onroad heavy-duty diesel vehicles. Only now the scope must include regulations upon the fuel refiners to produce cleaner burning vehicle fuels that will ensure the proper operation of the new model engine emission controls, and will markedly reduce the by-products of combustion from existing equipment that uses these new diesel fuels.

The Transition to Ultra-Low Sulfur Diesel Fuel

Just about the same time that <500 ppm sulfur diesel fuel will be required in the nonroad markets, the fuels for heavy-duty on-highway vehicles will begin a transition to an ultra-low sulfur content of less than 15 ppm sulfur. This is because EPA finalized a new rule last year to reduce emissions of nitrogen oxides (NOx) and particulate matter (PM) from heavy-duty highway diesel engines that require the introduction of catalyst-based exhaust aftertreatment emission controls. The new rule requires refiners to produce highway diesel meeting a 15 ppm maximum starting June 1, 2006, because the new emission control hardware will be damaged if run on a diesel fuel of any higher sulfur content. Under a temporary phase-in provision, up to 20 percent of highway diesel produced may continue to meet the 500 ppm sulfur limit through May 2010; the remaining 80 percent of the diesel fuel produced for highway use must meet the new 15 ppm maximum.

There will be a significant cost impact on refiners who choose to remain in the on-highway fuel market and make the 15 ppm ultra-low sulfur fuel, since major changes and investments will have to be committed at the refinery to enable the removal of this much sulfur. Moreover, only the new 2007 and later model heavy-duty diesel trucks will require the use of the 15 ppm fuel, while those fleet operators with existing vehicles will prefer to run on the 500 ppm fuel and avoid the higher cost 15 ppm fuel when possible. However, the 80/20 production ratio imposed by EPA will drastically limit the supply of the 500 ppm fuel to truckers, and may have the spillover effect of driving up the price of this fuel for those who need to purchase it for off-highway applications.

EPA has already signaled its intention to require the same types of emission controls used for on-highway to be applied to nonroad equipment in the 2009 to 2010 timeframe. It is expected that the 15 ppm highway grade diesel will have to be required in the off-highway markets by that time to enable the use of these new aftertreatment emission control technologies on nonroad equipment. Oil industry representatives project that the demand for 15 ppm sulfur diesel will eventually supplant the 500 ppm diesel entirely by the year 2020.

Important Diesel Fuel Properties

Diesel fuel for today's engines is required to:

- Provide energy for power and fuel economy
- Allow easy start up
- Flow readily in cold temperatures
- Protect the fuel delivery system
- Provide low emissions

Engine design is the most important factor leading to power and fuel economy. However, fuels with a higher energy density will exhibit improved power and lower fuel consumption. Conventional Diesel No.2 has one of the highest energy densities.

Cetane number is the measure of the ignition quality of the diesel fuel. In order for a diesel engine to start easily, the fuel must have a sufficiently high cetane number. The fuel standard that governs diesel fuel (ASTM D 975) calls for a minimum cetane number requirement of 40. There is continuing debate whether cetane values above this level improve engine performance.

The waxy materials found in all distillate products, which at low temperatures can crystallize and plug fuel filters, govern low temperature operability. The *cloud point* of the fuel measures the first appearance of the waxes, although filter plugging will not typically occur until the ambient temperature is 5 to 10^{o} F below the cloud point. The most common approach to dealing with winter operability is blending a No. 2 fuel with No. 1 to lower its cloud point. Alternatively, the use of wax-modifying additives can give equivalent operability benefits as No. 1 fuel blending without the associated power and fuel economy losses.

Most No. 2 Diesel fuels provide adequate protection against fuel pump and injector wear. There have been instances, especially with ultra-low sulfur fuels or those with very low aromatics levels, where the inherent lubricity of the fuel was inadequate to protect against accelerated fuel pump and injector wear. Ultra-low sulfur fuels will require some form of lubricity additive.

By far, the most important aspect leading to lower exhaust emissions is engine design and its associated emission controls. Fuel composition, however, does play an important role. *The sulfur content of diesel fuels for use on-highway is regulated to low levels by the federal government and several states to help reduce pollutants and enable the effective use of certain emission control systems. EPA expects to impose similar rules for diesel fuels used in nonroad equipment.*

Will Existing Equipment Operate Reliably on Low Sulfur Diesel?

It's not uncommon to have 10 year old, or even 20+ year old nonroad equipment on farms and construction sites. A new fuel's compatibility with older existing machines is a critical concern. Because the 500 ppm diesel has been introduced in on-highway trucks since 1994, its operating characteristics are fairly well known.

Low sulfur diesel fuel may be produced in a number of ways. One of the most cost effective processes involves the introduction of hydrogen in the refining process to remove sulfur and reduce aromatic hydrocarbons. The net result of hydro-processed low sulfur diesel fuel has been a reduction in its inherent lubricity. This loss of lubricity can result in high rates of fuel injection component wear and potential premature failure. Field experience with these fuels has led to the widespread use of lubricity additives that are introduced at the fuel distribution terminal or as an aftermarket fuel treatment.

The 1994 introduction of the 500 ppm diesel fuel for on-highway was not without some early incidents of fuel system problems. Some of the existing heavy-duty truck engines experienced a failure of the fuel system seal materials when exposed to the new fuels after having been powered with traditional fuels. Many manufacturers have reported that all the seals throughout the parts distribution system have now been purged and replaced with newer seal materials that are resistant to the low sulfur fuels.

These same experiences will need to be addressed once ultra-low 15 ppm sulfur diesel is introduced on a widespread basis beginning June 2006. Achieving these near zero sulfur levels requires refiners to perform more severe hydrotreating, but this can also adversely affect other fuel properties. Ultra-low sulfur fuels can lose natural antioxidants that help prevent the fuel from forming gums and sludges. A fuel's antioxidation properties are particularly important in modern fuel systems, where the fuel is exposed to higher operating temperatures. Ultra-low sulfur fuels can also be more corrosive than conventional diesel, requiring corrosion-inhibiting additives.

Another issue will be the reduction in fuel density resulting from the hydrotreating process. This translates to a slight lowering of the energy content and a subsequent increase in fuel consumption. On the other hand, the ultra-low sulfur fuels should improve equipment cold startability, reduce white smoke during warm-up and prolong the period allowed between engine oil changes.

How Much Will Ultra-Low Sulfur Diesel Cost?

According to a Department of Energy study, the cost of producing 15 ppm highway ULSD will increase from 4.7 cents to 9.2 cents per gallon. A similar study conducted by the American Petroleum Institute projected the 15 ppm diesel sulfur rule will increase the cost of highway fuel by approximately 13 cents per gallon over today's 500 ppm highway diesel. You would need to add another 1 to 3 cent incremental cost per gallon if you wish to compare this with nonroad high sulfur diesel fuel. These figures, however, do not include distribution costs and taxes. The pump price, therefore, would exceed this estimated increase.

This may all be a moot point in that as EPA introduces more stringent emission controls for off-highway sources of pollution, you may be limited in your choice of what diesel fuels you can purchase. Furthermore, a nonroad operator will have a dilemma once the first low emission piece of equipment is purchased, since it will require the use of low sulfur fuel. Will you want to handle a separate diesel fuel to accommodate just those newer machines in your fleet? It's more likely that you will just bite the bullet and changeover completely to the more expensive low sulfur fuel to avoid the added investment in tankage and headaches in handling, as the ultra-low sulfur fuel with lubricity additives will work in all of your machines.

BIODIESEL

Biodiesel is the name for a variety of ester-based oxygenated fuels made from soybean oil, other vegetable oils or animal fats. Biodiesel is a popular renewable energy alternative to petroleum-based diesel that's 'cropping up' in America's heartland. The concept of using vegetable oil as an engine fuel dates back to 1900 when Dr. Rudolf Diesel demonstrated his engine at the World Exhibition in Paris using peanut oil as fuel.

Biodiesel has been appropriately characterized as "liquid solar energy." Biodiesel is produced from renewable oilseed crops, such as soybeans, that are grown and harvested repeatedly in what experts call a closed loop carbon cycle—as they grow these oilseed crops take up carbon dioxide and then release it back into the air when biodiesel is burned. In a joint study, the U.S. Departments of Energy and Agriculture found biodiesel reduces CO_2 greenhouse gases produced by 78% over its entire life cycle compared to petroleum diesel, and has a positive energy balance of 3.2 to 1 (i.e., 3.2 units of energy are produced for every one unit of energy needed for biodiesel production, while diesel fuel's is 0.83 to 1).

Biodiesel's Attributes

Across the globe environmental concerns and energy security issues have prompted legislative actions spurring the demand for alternative fuels to displace petroleum-based fuels. That all said, the biggest roadblocks to the widespread use of most alternative fuels are the need for engine modifications, suffering a loss in equipment performance and requiring capital investment in new fuel supply infrastructures. Biodiesel has many positive attributes associated with its use as an alternative fuel, but by far the most notable asset highlighted by fleet managers is its similar operating performance compared to conventional diesel fuel and the absence of any changes required to the engines, facilities or maintenance. Because it has similar properties to petroleum diesel fuel, biodiesel can be used alone (known as B100 grade) or mixed in any ratio with petroleum diesel fuel.

Biodiesel has many advantages as a vehicle fuel. For example, producing biodiesel from soybeans or other domestic crops reduces the United States' dependence on foreign petroleum, increases agricultural revenue, and creates jobs. It's no wonder that the sales of biofuels are increasing especially in agricultural areas where the adage, "Grow your own," takes on a new context. Many federal and state fleet vehicles are already using biodiesel blends in their existing diesel engines.

In addition to its contributions to reduced global warming, the use of biodiesel in a conventional engine, either as a pure fuel or blended with diesel fuel, results in a reduction of unburned hydrocarbons, carbon monoxide, and particulate matter. Emissions of nitrogen oxides, which lead to the formation of ozone, are either slightly reduced or slightly increased depending on the duty cycle of the engine and its design. When burned in a diesel engine, biodiesel replaces the exhaust odor of petroleum diesel with the pleasant smell of popcorn or French fries.

Performance

Biodiesel has slightly less energy content and a higher cetane number than the average diesel fuel used in the U.S. However, in over 15 million miles of in-field demonstrations, biodiesel showed similar fuel consumption, horsepower, torque and haulage rates as conventional diesel. When biodiesel is blended with conventional diesel in proportions of 20% or less, any differences in engine performance are nearly imperceptible. The standard mixture for biodiesel fuel in public transportation fleets and other programs is 20% biodiesel, and 80% conventional diesel fuel. This standard mixture is known as B20.

Biodiesel provides significant lubricity improvement over petroleum diesel fuel. Even the blending of as little as 1 percent biodiesel can provide up to a 30 percent increase in a diesel fuel's overall lubricity. Currently, at least seven companies are marketing a premium diesel fuel grade containing proprietary additive packages that feature biodiesel as a lubricity component.

Compatibility of biodiesel with engine components can be a concern to nonroad operators. Biodiesel will soften and degrade certain types of elastomers and natural rubber compounds over time. The use of high biodiesel percent blends can attack fuel hoses and fuel pump seals. There has been promising research carried out by the Agricultural Research Service involving mixing additives with biodiesel that could overcome this problem. However, due to similar materials issues discovered with low sulfur diesel fuel, the experience has caused many OEMs to changeover to materials suitable for use with biodiesel. While the problem solving technology is available, new biodiesel users should contact their equipment manufacturer for specific information.

Cold weather can cloud and even gel any diesel fuel, and biodiesel and its blends are no exception. Users of a 20 percent biodiesel blend could experience a degradation of the cold flow properties (e.g. cold filter plugging, cloud point) where gelling of the B20 will occur approximately 3 to 5 ^{o}F. sooner than with conventional No.2 Diesel. All the same precautions employed for conventional diesel are necessary when fueling with biodiesel.

Another major concern with biodiesel fuel is its shelf life, termed its *Stability*. Whereas, it is true that all fuels, including No. 2 diesel have storage limits, the high oxygenate content of biodiesel makes it much more susceptible to oxidation break down into gummy residues and varnish that can lead to filter plugging or injector deposits. The storage limit for biodiesel blends are similarly affected and varies in proportion to the blend percent and the ambient temperature at which these fuels are stored. It's best to talk with your fuel distributor to determine the recommended storage limits for your particular fuel and set of circumstances. Various anti-oxidation additives are under development for biodiesel that can take some of the guesswork out of the stability concerns.

Biodiesel Economics

Most of the discussion to this point has presented data based on testing 100% biodiesel fuel, but B100 is too expensive at this time (about $3.00 a gallon) to be considered as a total replacement for diesel in most nonroad applications. The most common blend is a mix of 20% biodiesel with 80% petroleum diesel, or "B20," while there are a host of other blends as well like B10, B5 and others. Depending on which supplier you talk to, the cost of the most popular 20/80 biodiesel blend can vary from 20 to 40 cents more per gallon than No. 2 Diesel. The observed reductions in emissions with biodiesel blends will be diminished in direct proportion to the ratio of biodiesel to conventional diesel in the blended fuel.

Beginning in November 1998 with the passage of the federal Energy Policy Act (EPACT) amendments that allowed biodiesel greater access to the alternative fuels market, it has become one of the fastest growing alternative fuels in the country. Moreover, it is recognized that biodiesel could be included as a low level blending component in ultra-low sulfur diesel fuel as a means to improve its lubricity while providing environmental, economic, and energy security benefits at the same time. If just 1 percent biodiesel were blended with the highway diesel fuel pool, over 300 million gallons of biodiesel production would be required. To produce 300 million gallons of biodiesel fuel would take approximately 194 million bushels of soybeans. This figure is based on the assumption that 7.3 pounds of soybean oil is required to produce one gallon of biodiesel, and that there are 11.3 pounds of soybean oil in one bushel of soybeans.

Warranty Implications With Use of Biodiesel Blends

Biodiesel enjoys the support of the Fuel Injection Equipment industry as an option to solving the lubricity problem with low sulfur diesel. The inclusion of low levels of biodiesel in diesel fuel would eliminate the inherent variability associated with the use of other types of additives. They have stated that: a) lubricity testing has shown that up to 2% biodiesel is sufficient to ensure the lubricity of any distillate fuel; and b) since biodiesel is a fuel itself, there are no technical issues related to overdosing that are present with conventional lubricity additives. Most major diesel engine manufacturers have affirmed that the use of B20 or lower blends will not void their engine warranties, and they are actively working with the biodiesel industry on further research and development activities.

> As a precaution, nonroad equipment operators should always consult with the equipment manufacturer before using 100% biodiesel or any biodiesel blended fuels to ensure compatibility with the engine's fuel system components and the equipment's warranty. And when ordering biodiesel fuels, always inquire of your supplier if the biodiesel fuel they are selling meets ASTM provisional specification PS 121 to insure its quality as a motor fuel.

ETHANOL DIESEL BLENDS – E-DIESEL

Some research interest has been shown in yet another renewable liquid energy source, Ethanol, and its potential role in displacing increasing amounts of petroleum diesel, although its current use is primarily as an additive to gasoline. Ethanol is a renewable fuel produced from biomass materials such as corn and other high starch containing crops. Laboratory tests and in-the-field demonstrations have indicated that ethanol-diesel blends offer measurable improvements in environmental quality through reduced exhaust emissions. Furthermore, there is an established infrastructure for the production of corn-based ethanol that is partially subsidized by fuel tax incentives.

These ethanol-diesel blends are called "E-Diesel" or sometimes "Oxydiesel." One of the major hurdles being addressed is that ethanol does not readily combine with diesel fuel. Recent advances have produced a "flash-mixing" blending agent that enhances the assimilation of ethanol with diesel fuel. Like biodiesel, E-Diesel has the potential for being used interchangeably with conventional diesel fuel in standard engines.

Performance Issues

Unlike biodiesel blends, there is a perceptible loss in performance when switching over to E-Diesel due to the lower energy content found in ethanol. Furthermore, a standard diesel engine will not operate on straight ethanol without significant modification and a loss in power output of the engine. In testing performed by a University of Illinois team with a 10% ethanol/diesel blend in a pair of matched farm tractors, the E10-fueled machine showed increases in fuel consumption of 4 to 5 percent compared to the same tractor run on No. 2 diesel, which was roughly equivalent to the reduced energy content of the blend. In addition, a power penalty was observed between the two tractors when engine loading increased beyond that of typical tasks.

There are a number of other issues associated with the use of ethanol-diesel blends in diesel engines. The addition of ethanol, without the inclusion of an additive package, reduces the cetane value of the fuel, decreases its lubricity, and has a tendency to absorb water and be less stable than conventional diesel. Furthermore, there is some concern that a safety issue exists when storing ethanol-diesel due to its low vapor flash point, to the extent that a combustible mixture may exist in the fuel tank of the equipment using it.

Ethanol Economics

The U.S. Department of Energy is currently supporting demonstrations relating to the further development and commercialization of E-Diesel. A preliminary estimate suggests that the cost of a 15% E-Diesel fuel blend could range from 5 to 7 cents more per gallon over No. 2 diesel. It's believed that the associated economic benefit to corn producers derived from the increased demand for corn could compensate for the higher cost of running on E-Diesel fuel. However, to date, ethanol's favorable fuel tax treatment has been the main impetus in the development of ethanol into a two billion gallon per year industry. It is expected that the majority of ethanol production will continue to be utilized as an oxygen containing blending component for reformulated gasoline.

OTHER ALTERNATIVES TO DIESEL FUEL

Chemists have been able to synthesize an extremely high quality diesel fuel since the era of World War II. This fuel, known as Fischer-Tropsch (say Fisher Trow-p-shh) diesel, is a synthetic fuel produced from the conversion of natural gas into a liquid. It is also known as GTL diesel, where the acronym refers to "gas to liquid" conversion. Natural gas is not the only feedstock that can be utilized. The gas to liquids process can be generated from any hydrocarbon rich medium including coal and biomass resources, and government sponsored research programs are expanding for these reasons.

The gas to liquids process for synthesizing fuel is very expensive, and therefore is primarily limited to those locations around the world where natural gas deposits are stranded in remote locations or a nuisance by-product of crude oil production. The theory being, the cost of making Fischer-Tropsch fuel begins to approach economic viability if the feedstock (natural gas) is free.

Properties

The resulting fuel is superior to crude-oil based diesel in several ways including: the high cetane number, the elimination of aromatics and a near zero sulfur content, which all combine in making Fischer-Tropsch diesel an ideal low emissions fuel. GTL processed fuel can be blended with conventional diesel fuel to make a cleaner diesel fuel with superior properties, and thus augment the U.S. refineries' capacity for producing clean diesel fuels. Opportunities are being investigated to demonstrate the benefits of GTL blended fuels in California and other severe non-attainment locales to reduce the emissions from existing vehicles and equipment.

CONCLUSIONS

It is certain that new diesel fuels will be required in the nonroad sector, some driven by environmental regulation, as in the requirement to use low sulfur diesel, and some alternative fuels driven by a combination of energy security and economic opportunity. America's dependence on foreign oil has been increasing at an accelerating rate due to lower domestic production and expanding energy needs. The United States currently imports 57% of its energy making petroleum imports the single largest component of our trade deficit. Recent political unrest in the Middle East with the potential for curtailments in crude oil supplies may accelerate the necessity for immediate changes in America's energy policy towards increased support of alternative sources of energy.

The U.S. Congress has already proposed legislation calling for the mandatory introduction of 'renewable fuel' -- such as biodiesel, ethanol or biogas -- in motor vehicle fuel sold into commerce beginning in calendar year 2002. The proposed Renewable Fuels for Energy Security Act's main intent is to use renewable biosources of energy to reduce the quantity of fossil fuel present in a fuel mixture used to operate a motor vehicle. One proposed bill calls for a refiner, blender, or fuel importer to ensure on a 6-month average basis that motor vehicle fuels contain not less than 0.8 percent renewable fuel beginning with calendar year 2002 and increasing in percentage every year until it reaches a requirement of 5.0 percent in 2016 and thereafter.

Similarly, the European Union (EU) is considering a mandate that will increase the production of biodiesel fuel. The EU's Directorate for General Transport and Energy has drafted a proposed rule that would require biofuels to account for 2% of each member country's transportation fuels by 2005. The proposed biofuel mandate would then increase to 5.75% of transportation fuel by 2010. Between the date of implementation and 2009, each country could meet the mandate's provisions either through the production of conventional/biofuel blends, or the use of pure biofuel. The proposal must be approved by the EU Council of Ministers and the EU Parliament, a political process that could take up to two years to complete. Europeans will more likely than not use ethanol and biodiesel as their two primary biofuels. Whereas most biodiesel fuel in the United States is produced from soybean oil, most of the biodiesel produced in Europe is made from rapeseed oil.

Renewable sources of energy, which include biofuels production, may hold the most plausible answer to our long-term energy security. The greatest driving force for the use of biodiesel and ethanol-diesel blends is the need to have a fuel that fulfills all of the environmental and energy security needs previously mentioned and does not sacrifice equipment operating performance, while simultaneously providing an increase in agricultural revenues and job creation. New diesel fuels that support these objectives will be in the future for owner/operators of farm and construction equipment.

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