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BELL PERFORMANCE FUEL ISSUES SERIES: BIODIESEL PRIMER – THE GOOD AND THE BAD

EXECUTIVE SUMMARY

Biodiesel (fats converted into fuel) has become a significant player in the fuels marketplace, with production and use increasing exponentially since the mid-to-late 2000s. Biodiesel blends offer environmental and operational benefits for consumers, including increased cetane and lubricity, and lower emissions. Biodiesel's largest drawbacks are storage instability and gelling in cold weather, which can vary substantially depending on the type of oil from which the biodiesel was made.

WHAT IS BIODIESEL?

"Biodiesel" is a fat that has been modified through a series of reactions, resulting in a chemical that can be burned in a diesel engine as fuel in place of conventional #2 diesel fuel.

Contrary to the terms that are thrown around in the marketplace and on Internet message boards, the term "biodiesel" refers only to the actual "FAME" chemical that results from the chemical conversion of fat into fuel. The legal definition of biodiesel is "a long chain fatty acid ester containing only one alcohol molecule on one ester linkage". The acronym "FAME" stands for "fully alkylated methyl ester".

The sole term "biodiesel" always refers to the 100% FAME product. Pure biodiesel is also referred to as B100 (100% biodiesel). When biodiesel is mixed with diesel fuel, you get a "biodiesel blend" that is designated as "Bxx", relating to the percentage of biodiesel within the overall blend. B2, B5, B11 and B20 are the most popular and commonly found blends. Blends above 20% are less commonly found because engine manufacturers do not warrant their engines to run on blends above 20% biodiesel. If you stick to B5 and that fuel is in specification, it is illegal for an engine manufacturer not to honor the warranty.

B2 and B5 are very commonly found in states that have a biodiesel mandate, such as Minnesota and Louisiana. It should also be noted that in many states, it is legal to blend up to 5% biodiesel into petrodiesel fuel and not disclose the biodiesel content on the labelling. This means that many diesel users are already using low-level biodiesel blends on an everyday basis, without realizing it.

Some consumers talk about putting straight raw vegetable oil or animal fat in their vehicle, referring to this practice as burning biodiesel fuel. However, raw vegetable oil chemically contains three ester linkages (instead of just one) and therefore is not legally defined as biodiesel. Raw vegetable oil has a different viscosity than biodiesel or diesel fuel (up to 10x more), and burning it in a diesel engine leads to big time engine deposits, ring sticking and lube oil dilution. This is true even if you just extend out your fuel by adding as little as 10% raw oil. The chemical conversion that turns raw vegetable oil into biodiesel FAME reduces its viscosity to that of diesel fuel, enabling it to burn like diesel does in the engine. Putting straight unconverted vegetable oil into your vehicle or boat is a recipe for engine problems and disaster, no matter what these people say.

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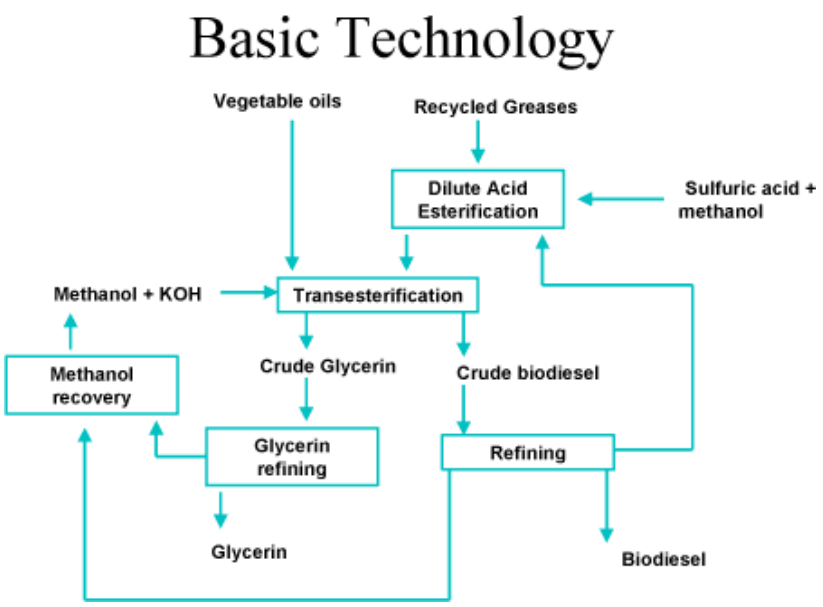
HOW DO YOU MAKE BIODIESEL?



The basic recipe for biodiesel is:

> *100 units plant/animal oil + 20 units alcohol + catalyst → 100 units of FAME feed stock + 10 units of recovered alcohol + 10 units crude glycerin.*

Another way to produce biodiesel is to take 100 lbs fat + 10 lbs short-chain alcohol (like methanol) + a catalyst (sodium or potassium hydroxide) to get 100 lbs of biodiesel (about 13.5 gallons) and 10 lbs of glycerin.

These processes speak to why biodiesel production is relatively popular – the ingredients are cheap and easy to find and the reaction processes are simple. The catalyst for the reaction is sodium hydroxide, and the short-chain alcohol most commonly used is methanol, both cheap and easy to find. The downside to all of this is it is also easy for the small-time "backyard" biodiesel producer to produce biodiesel that of "out-of-spec" if they are not careful in their processes. The consumer can avoid these issues by only buying their biodiesel blend fuel from reputable suppliers.

BENEFITS OF BIODIESEL USE

Biodiesel blends offer some great benefits for consumers:

1. Higher cetane

B100 has a higher cetane number than most conventional diesel fuels; high cetane rating means easier starting for diesel engines and is comparable to the octane rating of gasoline. The cetane increase varies by the type of feed stock used to manufacture the biodiesel. Highly saturated fuels made from animal fats (like leftover frying animal grease) can have higher cetane ratings as high as 70; polyunsaturated feed stocks (including soy and rape seed) are lower, closer to a 47 cetane rating. Of course, this cetane

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increase is blunted by the proportion of the biodiesel mixed into the blend – a B5 only has 5% biodiesel in it, so the cetane increase is only 5% of what it would have been at B100.

2. Low Sulfur Content

Biodiesel is naturally low sulfur, which makes it easy to incorporate into a fuel system without running afoul of the stringent ultra low sulfur diesel regulations, where sulfur content is capped at a mere 15 parts per million.

3. Superior Lubricity

Mixing biodiesel into ultra-low sulfur diesel solves one of ultra-low sulfur (ULSD) diesel's biggest problems – its lack of lubricity. Removing the sulfur from diesel fuel destroys many of the substances in the fuel which enable it to lubricate engine parts like injectors and fuel pumps. But adding as little as 2% biodiesel to a fuel blend gives 66% more lubricity to #2 diesel than before.

However this lubricity increase is not a linear one, as the curve of added lubricity benefit to percent biodiesel levels off as the composition approaches just 2.5%. So there is no additional benefit of added lubricity when comparing a B5 or a B20 to just a B2 blend.

Still, 66% more lubricity is a wonderful benefit to have.

4. Cleaner Emissions

This is the biggest reason why cities and government entities have recently started to include more biodiesel in the fuel supplies for their municipal and transit fleets..

Most large urban areas already fail EPA air standard qualities, putting them at risk of government action which could force them to adopt measures to improve air qualities or else lose federal monies. Taking action like switching to biodiesel blends can help meet these standards, and is also a good PR move, making the local government appear to be more concerned about green issues.

What emissions benefit does biodiesel use give? Depending on the blend percentage, biodiesel combustion results in lower emissions for most measured emissions related to hydrocarbon combustion. Unburned hydrocarbons and particulate emissions (the nasty black smoke you can see coming from the stacks of diesel big rigs) drops as much as 47-67% over straight diesel fuel alone.

Biodiesel emissions have lower levels of polycyclic aromatic hydrocarbons (PACs) and other harmful carbon ring compounds than conventional diesel fuel. A B20 blend will lower those harmful compounds by 20-40%. This is a good thing because PACs have been linked to causing cancer.

NOx emissions are also targeted by the EPA because NOx contributes to ozone production and poor air quality in urban areas (ozone in the sky is good; ozone on the ground hurts your lungs). Biodiesel has a neutral to slightly negative effect on NOx emissions; however, these figures are in dispute by some groups like the National Biodiesel Board and so research is still ongoing.

The story is different when you go from a truck or boat to burning biodiesel in a home heating boiler system. NOx does decrease when biodiesel is burned in **boilers/home heating oil**, due to burner differences. When blended into heating oil, NOx emissions are reduced by 1% for each 1% biodiesel blend added. This reduction happens no matter what kind of feed stock used to make it..

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PROBLEMS/DRAWBACKS WITH BIODIESEL USE

1. Less BTU energy value than Diesel = Less Mileage

Relative to weight, the biodiesel FAME molecule contains less energy than a diesel hydrocarbon chain molecule. Less energy and lower heat of combustion results in lower mileage.

How much this drop is depends on who you ask and sometimes can be overstated. B100 contains 8.5% less energy per gallon than diesel fuel. The biggest part of the energy difference is due to the FAME containing 12% greater oxygen – more oxygen instead of carbon. When you factor in differences in density, this energy difference is reduced to 8.5%, apples to apples.

Typical energy values for the two fuels are 118,170 BTU for B100 vs 129,050 BTU for #2 diesel. However, at lower blending ratios like B20, the drop is not noticeable by most drivers, since 80% of the blend is now diesel fuel. So when using B20 or B5, you'll get some mileage drop, but it's not going to be on the order of 10 or 20% like some claim.

2. Cold Flow problems

The cold flow properties of biodiesel blends are highly dependent on the feed stock from which the biodiesel was made. The level of saturation is the biggest factor here. Highly saturated feed stocks (palm oil, coconut oil, animal fats) have the worst cold flow properties but are the most stable. The opposite is true for polyunsaturated feed stocks (rape seed, corn, canola oil) – they gel less in cold weather but are the most unstable.

A typical B20 blend has a gel point 3-10 degrees F higher than regular diesel. The cloud point for most B100 starts at 30-32 deg F for mono- and poly-unsaturated feed stocks (most vegetable oils) but can be up to 80 deg F for animal fats and highly saturated frying oils. When the fuel hits the cloud point, it gets hazy and will start the chain-reaction processes for gelling.

Also problematic is that the biodiesel pour point is only a few degrees lower than the cloud point. So when the fuel starts clouding up, it's going to gel up and become thick only a few degees below that. For example, soy FAME (pure B100) has a cloud point of 38 degrees F, CFPP of 28 and a pour point of 25 F. Other differences between cloud point and pour point are usually 8-10 degrees F total – not very much.

If feasible, gelled biodiesel can be restored by heating the fuel to dissolve the precipitated crystals. To get crystals back into solution, the fuel needs to be warmed back up to 100-110 deg F to melt the most highly saturated crystals back into solution. However this does not help you if you are stuck in the middle of nowhere with a tank full of gelled biodiesel.

3. Materials Compatibility

Nitrile rubber, polypropylene, polyvinyl, Tygon are all susceptible to attack from B100

- Biodiesel blends higher than B20 can damage hoses and pump seals.
- Blends lower than B5 have no effect

Materials compatibility is more of a problem in old engines made before 1993. Engines made after 1993 are less likely to have these susceptible materials in them. In reality, the industry has done a satisfactory

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job in overcoming materials issues like these. Most contemporary engines and fuel systems won't be bothered by biodiesel.

4. Increased NOx Emissions

As mentioned before, biodiesel can increase NOx production in internal combustion engines, which is bad for urban air quality. Just how much this increase is can vary by feed stock; the difference in NOx emissions between high and low NOx feed stocks is about 15%.

The composition of biodiesel determines how much NOx is produced. More highly unsaturated feed stocks produce higher NOx levels. Vegetable oil feed stocks are the most unsaturated and animals fats or tropical oils are the least, so you would expect vegetable FAMEs like soy and canola to product the worst results on NOx emissions.

Why is this?

Some past research has indicated that the increased NOx production is related to differences in injection rates into the combustion chamber caused by biodiesel's higher "bulk modulus" (resistance to compression) and higher viscosity, which makes it less compressible than regular diesel. More technically, the higher bulk modulus and higher speed of sounds of biodiesel means the pressure rises faster in the fuel lines and develops an advance of nearly two degrees in injection timing in the engine. This in turn generates a faster pressure and temperature rise in the combustion chamber, leading to an increase in NOx.

It is apparent the best way to reduce NOx is by modification of engine technology. Retarding the engine timing by 1-5 degrees can bring B100 NOx down to diesel baselines or below. Unfortunately, the tradeoff for doing this is a reduction in power for the driver.

5. Effects on engine lubrication

Biodiesel use seems to have a negative effect on the engine lubrication. As proof, European engine manufacturers prescribe a 50-70% reduction in oil drain intervals with the use of blends above B5.
A practical reason for this might be that biodiesel's higher density and surface tension leads to more fuel dilution of the lubrication in the crankcase.

So if you use biodiesel and make a lot of short trips or drive in harsh or extreme conditions, it may be best to be more careful in how often you change your oil. Most manufacturers recommend every 5,000 to 7,000 miles on regular fuel. Using biodiesel could mean you need to err on the lower end of that scale.s

6. Cleaning Effects

The methyl esters in biodiesel have been used as low VOC (environmentally-friendly) cleaners for many year; they are excellent detergents. This is not always a good thing when you introduce them into a dirty storage or truck/boat fuel tank.

When first added to a fuel system, B100 dissolves any sediments present in the fuel filter and fuel storage tank and can cause fuel filter clogging and bursting, leading to injector deposits.

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It is recommended to clean tanks and fuel systems before first introduction of B100 to a system. Luckily, B20 is too dilute to have a similar cleaning effect. So the average consumer may not have to worry about this too much.

7. Stability Issues

The typical shelf life for B100 made from soy or canola oil is about four to six months in ideal conditions. Ultimately, the working storage life of biodiesel (like diesel) is dependent upon the storage conditions.

For biodiesel, cold flow properties and stability seem to be corollaries - biodiesel with good cold flow response have poor stability and vice-versa. Biodiesel is susceptible to oxidation from exposure to air, water, light and certain metals. When it undergoes these reactions, it first becomes hazy, and then forms a thick precipitate gel. Analysis of this gel shows that it is mostly made up of organic compounds that are directly produced by the "oxidative cleavage" of double-bonds in the biodiesel molecule. In other words, oxygen-containing compounds (including water) will chemically attack biodiesel and break it apart, producing a mixture of components that combine to produce biodiesel gel and sediment.

What causes biodiesel breakdown?

What kind of compounds can contribute to biodiesel instability and breakdown? Contact with air provides the oxygen necessary to fuel oxidation reactions that break the fuel down. Contact with water causes the biodiesel to hydrolyze and form organic acids, which are partly responsible for the compatibility problems with various rubbers. Contact with metals like tin and copper will degrade biodiesel and create sediments.

Now one might think that these instability effects are lessened if you simply dilute biodiesel in a B20 or less blend. But it is interesting to note that B100 does not produce sediments at the same rate that biodiesel blends like B5 and B20 will. This is because B100's higher viscosity and greater concentration of chemical bonds act to disperse and suspend these oxidative compounds, preventing them from working together to accelerate the chain reactions that lead to sediment formation. So, as a general rule, B100 is more stable than B20 and other biodiesel blends.

When discussing biodiesel fuel stability, it's common to hear terms like Thermal Stability and Oxidative Stability. Thermal Stability refers to the fuel's ability to resist breakdown when exposed to heat for periods of time. B100 FAMEs tend to have good thermal stability features, due to the feed stock use in common cooking applications. If thermal breakdown did occur, injector coking would be the most likely engine problem associated with the poor-quality fuel.

Oxidative Stability is the fuel's ability to resist oxidation when exposed to factors like air, water, and certain metals. This is the biggest weakness of biodiesel. One reason for susceptibility to oxidation is that the processing of some of the feed stocks can remove natural antioxidants from the compound. More highly saturated feed stock seems to be more resistant to this and have better oxidative stability.

Occurrences of biodiesel oxidation are even higher in erratically-used engines, such as generators and seasonal vehicles. Biodiesel blends that are stored for long periods of time accumulate water and are exposed to air and heat for long periods of time, and have the greatest chance of developing microbial contamination, which can produce further acids that accelerate fuel breakdown.

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Why is this bad for engines?

Biodiesel which has been oxidized in this manner does not burn anywhere near as well as fresh biodiesel. Running this kind of fuel through the engine gives poor combustion, leading to a drop in mileage. Because it does not combust cleanly, it will form deposits in the injections and in the combustion chamber, and this poor combustion also contributes to excessive emissions, meaning that you're going to lose some or all of the green emissions benefit you were getting by switching to biodiesel in the first place.

In addition to oxidative compounds like aldehydes and ketones, formic acid, acetic acid, other organic acids, water and methanol are common products produced by fuel degradation. These end products of the oxidation process may be harmful to fuel injector equipment and can cause problems such as injector clogging, corrosion of FIE components, gelling at low temperatures, and fuel seal failure.

COMPARISONS OF BIODIESEL FEED STOCKS

Increased demand and competition in the marketplace mean that people are making biodiesel from any feed stock they think could be suitable. As mentioned before, feed stocks give different characteristics to the biodiesel fuel, especially with respect to how stable they are and how well they resist gelling up in cold weather.

Saturated feed stocks have high stability and cetane ratings, but have a high cloud point, meaning they gel up at higher temperatures. Coconut oil, yellow grease and animal fats are examples of saturated oils

Monounsaturated feed stocks are in the middle of the pack, with medium stability characteristics, cetane rating and cloud point. Examples of these feed stocks are peanut oil and canola oil. Some yellow greases also fall into this category if they are high in both saturated and monounsaturated components..

Polyunsaturated feed stocks are most vegetables oils like soybean, corn and safflower oils. Biodiesel made from these oil have low cetane ratings and poor stability characteristics but are most resistant to gelling up in cold weather.

Intuitively one would think that different climates across the nation would spur producers to make biodiesel from only the feed stocks that give the cold flow and stability characteristics that are most advantageous for that climate. Animal fat biodiesels should work best in climates like Florida (never gets cold but is always humid). Vegetable oil biodiesels (less stable; better cold performance) should be preferred in the northern climates, whether it isn't as humid (better storage conditions) but tends to get colder.

However, the market will often dictate what a producer will use to make fuel, and that means low price and availability are the bigger concerns. That's true around the world, where different countries make biodiesel from what's available to them. In Canada, they use fish oil and beef tallow. Palm oil is commonly used in tropical countries like Ecuador and Indonesia. In Europe, rapeseed is kind. Everyone uses what works for them.

BIODIESEL SPECIFICATIONS

Only biodiesel FAME that meets all of the specification set down in ASTM D-6751 can legally be sold as "biodiesel". It is legally assumed that if the FAME meets specification and the diesel fuel meets ASTM D-975 specifications, then any biodiesel blend made from those fuels will be in spec. The law on biodiesel

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specification ensures that the fuel meets minimum requirements for properties like Flash Point (ensures that it burns properly in the engine), Acid Number (ensures the fuel has been properly made and is not already becoming unstable) and Free Glycerin (ensures all the waste glycerin has been washed from the fuel).

The ASTM specification includes these and about ten other properties. If the biodiesel is properly made, it will meet all these standards. If not, then it brings the potential for engine and performance problems for the consumer. As a consumer, buying your fuel from reputable suppliers will ensure your fuel meets this specification and won't give you any issues.

CONCLUSION

Biodiesel blends offer helpful benefits to consumers who are willing and able to side-step the issues associated with it. Many of these issues can be blunted by treating the fuel with an aftermarket product, of which there are many. As a consumer, you should expect many years of long-life from your equipment running on biodiesel.

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