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Biodiesel Use In Engines

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Biodiesel is an alternative fuel for diesel engines that is produced from renewable agricultural sources. Biodiesel is either a methyl or ethyl ester derived from vegetable oils, waste cooking oils or animal fat through a process called transesterification. In the U.S., soybean oil is the major vegetable oil used in producing biodiesel, but oils from crops such as canola, sunflowers, safflowers and others can be used as well. These oils contain varying proportions of fatty acids that affect their characteristics, especially the ability to flow in colder climates. Biodiesel can be used in any diesel engine with little or no modifications.

Biodiesel can be blended with diesel fuel in any proportion or used as a pure fuel (B100). Blended biodiesel, such as B20, is a 20 percent mix of biodiesel with 80 percent diesel fuel. Using pure biodiesel or any blend above 20 percent is **not** recommended as most engine manufacturers **do not** warranty engines using higher percentages of biodiesel. However, some engine manufacturers allow up to a 20 percent blend. Some states are requiring biodiesel to be mixed in small proportions (B2 in Minnesota) with diesel fuel for use in almost all diesel engines.

Government Action

The American JOBS Act of 2004 will play a major role in the development of the biodiesel industry. Congress established a tax incentive on biodiesel Jan. 1, 2005. The tax incentive provides distributors of biodiesel a $1-per-gallon subsidy for new oil (B100) or 1 cent for each 1 percent of biodiesel used in a fuel mix. Recycled cooking oil receives 50 cents per gallon for pure oil or a half cent per 1 percent mix.

These subsidies make B100 competitive in price to diesel fuel. Biodiesel usually is priced higher than No.2 diesel fuel, but the current subsidy allows biodiesel to be priced similarly to No. 2 diesel. The incentive does not go directly to the consumer; instead the subsidy goes to the biodiesel distributor. However, for fuel suppliers to remain competitive, the consumer likely will see most of the tax discount in less expensive biodiesel.

This tax incentive started at an excellent time. In 2005, the Environmental Protection Agency mandated a reduction of sulfur content in diesel fuel from 500 parts per million (ppm) to 15 ppm (Making Cents, 2004). Removing the sulfur from diesel fuel reduces the lubricity of the fuel, which could cause concern for the operator of diesel engines. Biodiesel is an excellent lubricant for the fuel injection system. The addition of as little as 1 percent to 2 percent (B1 or B2) would give diesel fuel more lubrication than previously accomplished with higher sulfur content diesel fuel.

Vegetable Oil Conversion to Biodiesel

The process of converting vegetable oil to biodiesel is relatively easy. The process requires alcohol (methanol or ethanol) with a catalyst (sodium or potassium hydroxide), which is added to vegetable oil and heated to slightly above 100 degrees Fahrenheit (38 degrees Celsius) with agitation. The conversion process occurs very quickly if an excess amount of alcohol is used. When the agitation is stopped, the glycerol settles to the bottom of the chamber and is drained off.

The next step is to remove any excess alcohol and catalyst from the biodiesel by washing with water. Most of the excess alcohol is evaporated during processing and usually is collected and distilled to sufficient purity for reuse. The basic process seems simple, but each step must be taken with great care to produce a high-quality fuel. Used cooking oil and animal fat also can be used, but with a slightly different process. The basic process is shown in Figure 1.

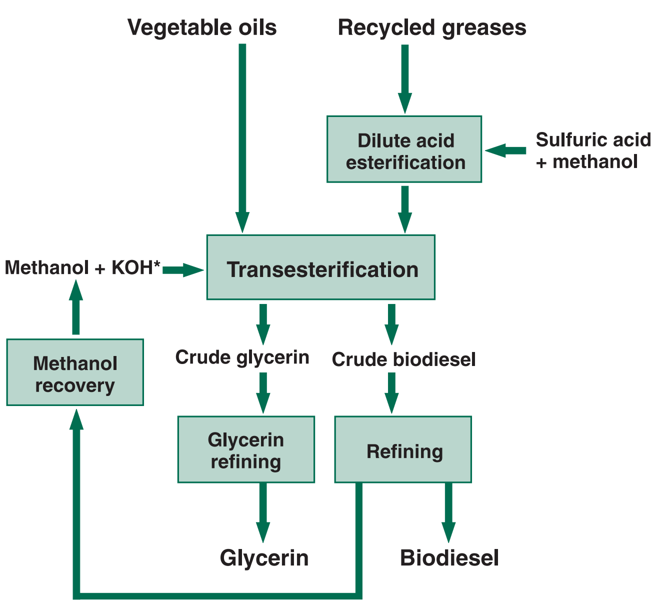

Figure 1. Basic Process Technology.

*Potassium hydroxide (KOH) or sodium hydroxide (NaOH) can be used.

Biodiesel in Cold Weather

In cold weather situations, biodiesel and No. 2 diesel can be mixed with No. 1 diesel to reduce the temperature at which gelling will occur. Gelling, or solidification of biodiesel and No. 2 diesel, is determined by the cloud point of the fluid. The cloud point is defined as the temperature at which a cloudy appearance is observed. However, biodiesel made from various vegetable oils (soybean, canola and sunflower) have different cloud and pour points, which is due to various fatty acid contents. The cloud point and pour point temperatures for biodiesel produced from oil crops grown in North Dakota are shown in Table 1.

The cloud point is the start of crystal formation in the oil. As the temperature is lowered, the crystals continue to grow until the oil is no longer a fluid but a solid. The temperature at which flow ceases plus 4.5 F is defined as the pour point. Usually, when the fuel nears the cloud point temperature, changes will need to be made to the fuel, such as the addition of anti-gel additives or No. 1 diesel fuel. Otherwise, filters will clog and stop the engine. The addition of a fuel line heater is another excellent method to prevent gelling of biodesel fuel.

Table 1. Cold flow properties of (B100) Biodiesel (Methyl and Ethyl Esters). (The Biodiesel Handbook).

Oil	Alkyl group	CP (°F)	PP (°F)
Canola	Methyl	33.8	15.8
Canola	Ethyl	30.2	21.2
Soybean	Methyl	32	28.4
Soybean	Ethyl	33.8	24.8
Safflower	Methyl	—	21.2
Safflower	Ethyl	21.2	21.2
Sunflower	Methyl	35.6	26.6
Sunflower	Ethyl	30.2	23
Rapeseed	Methyl	28.4	15.8
Rapeseed	Ethyl	28.4	5
Mustard Seed	Ethyl	33.8	5
No.1 Diesel		-35	-45
No.2 Diesel*		Variable	Variable

CP - Cloud Point; PP - Pour Point

*The cloud and pour point of the fuel varies based on the ambient (outside) temperature of where the fuel is used. This is determined and specified by the fuel supplier.

Commercially available (soybean) biodiesel (B100) will gel at about 30 F. Biodiesel made from other oil crops (such as canola-based biodiesel) will operate at lower temperatures.This is due to the difference in the degree of unsaturation of the fatty acids of the oil. Vegetable oils consist of numerous fatty acids. Some common examples are palmitic, stearic, oleic, linoleic and linolenic.

Mixing No.1 diesel fuel with biodiesel will help reduce most fuel gelling problems. Other measures may include the addition of fuel-line heaters or in-tank fuel heaters, along with the use of anti-gel additives. Insulating the fuel filters and fuel lines from the cold also will help. These measures should eliminate most cold-weather operational problems associated with biodiesel.

Research shows that biodiesel will have a storage life similar to diesel fuel, which usually is six months to one year. A two-year study completed at the University of Idaho found that biodiesel had slight deterioration and will store similarly to No.2 diesel fuel. Biodiesel mixtures of any blend should store during warm and cold months with little problem of separation of the biodiesel from the diesel fuel.

Two types of ester fuels can be produced. They are either a methyl or ethyl ester, and which it is depends on the alcohol that is used (either methanol or ethanol). At the current time, all commercially available biodiesel is methyl ester of soybean oil. This is because it is the most reasonably priced. Ethyl ester is made with ethanol, which is an extender for gasoline and will cost slightly more than methyl ester.

Biodiesel Potential In North Dakota

In 2004, about 96 million gallons of diesel fuel were used to produce crops in North Dakota. Approximately an equal amount of fuel is used in other areas, such as transportation and heating.

North Dakota currently plants more than 3 million acres of soybeans, with a statewide average yield of 29 bushels per acre (bu/ac). Soybeans contain about 18 percent oil, and with a yield of 29 bu/ac, produce approximately 43 gallons of oil per acre.

Other oil crops grown in North Dakota include canola and sunflowers. About 1 million acres are planted annually with each of these crops. Canola and sunflower crops produce an oil content between 40 percent and 45 percent, which produces more oil per acre than soybeans. Each of these crops will produce between 75 and 85 gallons of oil per acre.

If all the oil in North Dakota's major oil crops were used to produce biodiesel, about 275 million gallons of biodiesel could be produced. Also, the meal from the oil extraction process is an excellent protein supplement for livestock feed. Table 2 shows the potential fuel from North Dakota's primary oil crops.

North Dakota has the potential to produce several million gallons of biodiesel if only part of the crop is converted into biodiesel. If a B20 blend were used, about 19 million gallons of biodiesel would be needed to be mixed with diesel fuel for agricultural use.

Canola-based biodiesel is not available in the U.S. But several biodiesel plants are in the planning stages and plan to use canola oil. Some new processing plants also plan to process sunflower seed.

Table 2. Potential Biodiesel Fuel from the Major North Dakota Oil Crops.
(North Dakota Agricultural Statistics, 2004)

Crop	Acres	Oil content (%)	Yield	Gallons (per acre)	Total potential gallons
Soybeans	3,030,000	18	29 bu/acre	43	130,290,000
Sunflowers	1,020,000	44	1,300 lbs/acre	78	79,560,000
Canola	960,000	43	1,410 lbs/acre	83	79,680,000

The conversion process of vegetable oil into biodiesel is very efficient. It is nearly a 1-to-1 ratio, which means 1 gallon of vegetable oil will produce almost 1 gallon of biodiesel.

Biodiesel is a relatively efficient producer of energy. Biodiesel provides about 3.3 British thermal units (Btu) of energy for every Btu put into growing the oil crop and processing the crop to biodiesel. A Btu is defined as the energy required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

During the 2005 growing season, North Dakota State University used canola-based biodiesel in tractors at the North Central Research Extension Center in Minot without problems. For biodiesel to be used successfully in a diesel engine, its quality must meet American Society for Testing and Materials (ASTM) standards or fuel system problems likely will occur. The biodiesel used at the North Central Research Extension Center was tested and met ASTM standards.

Some reports of diesel engine problems have shown up in North Dakota. They include plugged fuel filters and residue in the fuel tank. These problems have occurred on older tractors and some relatively new tractors. No one knows whether biodiesel is the cause of the problem or it is due to some other cause. Most reports indicate excellent results with biodiesel.

Biodiesel Use In Engines

Most engine manufacturers have added warranty statements indicating if biodiesel can be used in their engines. For example, John Deere and Caterpillar offer engine warranties that allow small percentage blends of biodiesel (B2 or B5) to be used. However, the fuel must meet ASTM specifications. Biodiesel is being used in, or being adopted for, most diesel engines.

As stated earlier, blends of B20 or less require little or no modification of the engine. If blends greater than B20 are being used, some modifications may need to be made for the engine to provide long life. Fuel lines, gaskets and fuel pump seals may need to be replaced on injection systems that were built before 1993 because biodiesel has been shown to cause deterioration of seals. One common replacement material for seals is Viton.

Biodiesel has characteristics similar to a solvent. It may remove deposits in the fuel system, which may plug fuel filters or cause deposits to accumulate in the fuel tank. Plugged fuel filters usually show up as reduced power. Replacing the fuel filter usually will correct the problem.

Issues on oil dilution also have raised questions on the use of biodiesel. Studies at the University of Idaho, University of Missouri and Iowa State University have shown that replacing diesel fuel with biodiesel did not cause any unusual wear of aluminum, iron, chromium and lead components. Biodiesel appears to have an engine wear rate similar to diesel fuel.

One hundred percent biodiesel (B100), center, and 100 percent soybean oil, right, are similar in color but very different in viscosity. Both differ in color from No. 2 diesel fuel, left.

Diesel engine operators should have the engine oil analyzed to check for excessive wear when an oil change is performed. Analyzing the oil after every oil change may not be necessary, but it should be done on an occasional basis so the operator can see if excessive wear is occurring in an engine. The oil test must be sent to a laboratory for analysis. A sample kit usually is available through implement dealers. Engine oil analysis is recommended whether an engine operator is using pure diesel fuel or biodiesel. If excessive wear is occurring, corrective action often can be taken before a major failure occurs. Excessive wear often is caused by an air intake or antifreeze leak.

Universities and managers of fleets of state and city buses, pickups, large trucks and tractors have done several studies on various mixes of biodiesel/diesel fuel. The results of these studies look promising.

One difference with using biodiesel compared with regular diesel fuel is power output. Biodiesel has a lower energy content than diesel fuel. No. 2 diesel fuel typically contains about 140,000 Btu/gallon, while biodiesel contains about 130,000 Btu/gallon.

Fuels with a higher heat of combustion (Btu content) usually will produce more power per unit of fuel than lower-energy fuels. As a result, an engine using a lower-energy fuel will require more fuel to produce the same power as diesel fuel. Since biodiesel has a lower energy content, it will require about 1.1 gallons of fuel to do the same work as 1 gallon of diesel fuel.

Two other important properties of fuels for diesel engines is cetane number and fuel viscosity. The cetane number is a method for determining the ignition quality of a fuel. Most farm tractor engine manufacturers recommend a minimum cetane rating of 40. But most fuel suppliers provide diesel fuel with a cetane rating of 45 to 50.

In general, high-cetane fuels permit an engine to be started easily at low temperatures and provide fast engine warmup without producing white smoke or misfiring. Also, a high-cetane fuel will help reduce the rate of varnish formation and carbon deposits, and eliminate combustion roughness or engine knock. The cetane value of biodiesel is similar to diesel fuel, which allows it to be used in diesel engines without major modifications.

Fuel viscosity is another important fuel parameter. Diesel engine injection pumps perform most efficiently when the fuel has the proper viscosity. Viscosity has an influence on the atomization of the fuel when it is injected. If the viscosity is too high, excessively high pressures can occur in the injection system. This will cause poor atomization of the fuel in the combustion chamber, which may cause deposits in the engine and especially around the piston rings. This is the case when raw or partially refined vegetable oil is mixed with diesel fuel. Biodiesel has a viscosity close to No. 2 diesel fuel and will eliminate this problem. Table 3 lists properties of several bio-based fuels, as well as No. 2 diesel fuel.

Table 3. Fuel Properties.

	Fuel Weight Lbs/gal	Heat of Combustion Btu/gal	Cetane No.	Viscosity Centistokes
No. 2 Diesel	7.05	140,000	48	3.0
B100	7.3	130,000	55	5.7
B20	7.1	138,000	50	3.3
B5	7.07	139,500	49	3.1
Vegetable Oil	7.5	130,000	35-45	40-50

Engine Emissions and Environmental Effects

Emissions of greenhouse gases and other pollutants into the air may be harmful to the environment. Research has shown that the use of biodiesel will reduce most engine emissions, such as sulfates and hydrocarbons. Engine emissions will vary with engine design. Table 4 shows average reductions of emissions with biodiesel.

With the reduction in some air pollutants, biodiesel could provide significant improvements to air quality and be better for the enviroment, especially in industrial areas and cities that have significant pollution problems. Also, the growing of oil crops to produce biodiesel will help recycle carbon dioxide in the atmosphere because plants use carbon dioxide for growth and to produce seed.

Biodiesel is nontoxic and much more biodegradable than diesel fuel. Biodiesel is the first alternative fuel to pass the evaluations of the EPA's health effects section under the Clean Air Act.

Table 4. Percent Change in Engine Emissions of Biodiesel as Compared with Diesel Fuel. (Biodiesel Handling and Use Guidelines, 2001)

Emission	B100	B20
Carbon Monoxide	-43.2%	-12.6%
Hydrocarbons	-56.3%	-11.0%
Particulates	-55.4%	-18.0%
Nitrogen Oxides	5.8%	1.2%
Air Toxins	-60 to -90%	-12 to -20%
Mutagenicity	-80 to -90%	-20%
Carbon Dioxide	-78.3%	-15.7%

Conclusion

Biodiesel is an excellent alternative fuel for diesel engines. North Dakota agricultural producers grow sufficient oil crops to supply the food market, plus extend diesel fuel supplies for agricultural production.

Biodiesel is an environmentally sound choice and has few drawbacks. The major problem is cold weather operation, but with proper precautions (mixing with No. 1 diesel fuel, installing a fuel line heater and using anti-gel additives), few problems should occur. Biodiesel mixed at low percentages with diesel (B5 or B10, 5 percent and 10 percent biodiesel mixed with diesel fuel) should have few operating problems and will help reduce the dependence on petroleum-based fuels.

Before using biodiesel, check with your engine manufacturer to be sure it allows the use of biodiesel without voiding the warranty.

Useful Web sites

Web sites that have a considerable amount of information pertaining to biodiesel can be found at:

www.missouri.edu/~pavt0689/index.html

www.biodiesel.org/

www.ndsoybean.org/

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For more information on this and other topics, see: www.ag.ndsu.edu

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