SOME PHYSIOCHEMICAL TESTS OF SUNFLOWER OIL AND NO. 2 DIESEL OIL AS FUELS

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The suitability of sunflower oil as a fuel for diesel engines was evaluated by determining the physiochemical properties of sunflower oil, No. 2 diesel and blends of both. This evaluation was accomplished by determining the American Petroleum Institute (API) gravity, cetane rating, heat of combustion, kinematic viscosity, pour point, cloud point, and water content of these fuels using methods specified by the American Society of Testing Materials (ASTM) for diesel fuels. These tests for petroleum products are designed to standardize results so comparisons can be made from one laboratory to another.

Source of Materials

Refined sunflower oil from the Honeymead Refinery in Mankato, Minnesota, was used in these tests. This oil was alkali-refined, degummed and winterized to remove waxes. Its free fatty acid content was 0.5 percent. The No. 2 diesel was obtained from local commercial sources. Samples of crude sunflower oil, extracted with a small expeller and filtered by the Agricultural Engineering Department of North Dakota State University, were also tested for cetane rating.

Three blends were made on a volumetric basis. The different samples were:

100% No.2 diesel (No. 2 D)
25% sunflower oil + 75% No. 2 diesel
50% sunflower oil + 50% No. 2 diesel
75% sunflower oil + 25% No. 2 diesel
100% sunflower oil (sfo)

All blends visually appeared to be homogeneous mixtures with no distinct phases. In testing for homogenety, the 50:50 blend was centrifuged and there were no signs of separation. It was then assumed that sun oil and diesel blended into a homogeneous mixture.

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API Gravity

API gravity is an index of the fuel density or weight per unit volume. Results in Table 1 shows that the gravity of sunflower oil is 21.77° API while No. 2 diesel is lighter with a reading of 35.12° API. When this gravity is converted to pounds per gallon, the vegetable oil has a density of 7.7 pounds per gallon and is 8 percent heavier than the diesel which weighs 7.07 pounds per gallon at 60°F.

The heavier weight of the vegetable oil will mean increased costs for handling and transportation. This may be partly offset by the less hazardous lower flash point requiring less stringent standards for handling than for the diesel.

Centane Rating

The ignition quality of the fuel affects engine performance, cold starting, warmup, combustion roughness, etc. ASTM D 613-79 describes the test for ignition quality by the cetane method. The cetane rating is a measure of the self-ignition quality of the fuel. For ASTM purposes, it is the percentage by volume of normal cetane in a blend with heptamethylnonane required to match the ignition quality of the test fuel. The cetane number is determined in a standardized, single cylinder variable compression ratio engine with special loading and accessory equipment.

Samples of commercially refined sunflower oil and NDSU crude were tested at AMOCO's laboratory at Whiting, Indiana. Samples of NDSU crude and a 50:50 blend of diesel and NDSU crude were tested at the Waukesha Engine Division of Dresser Industries in Milwaukee, Wisconsin.

The cetane rating of the oils tested by the CFR engine test method and the calculated rating for diesel are shown in Table 1. Sunflower oil not only has a lower cetane rating, but a kinematic viscosity that is much higher than No. 2 diesel. Engine tests indicate a cetane rating for the refined sunflower oil of 31.7 compared to a cetane rating of about 28 for NDSU crude filtered sunflower oil. The more viscous sunflower oil may cause poorer atomization and fuel line restriction. These factors could influence ease of starting and light load operation.

Cetane rating is related to the volatility of the fuel. More volatile fuels have higher ratings than those that are not as volatile. Crude sunflower oil contains more waxes and gums than the more refined oil, so it may not be as volatile. Although the minimum specified cetane rating for diesel fuels is about 40, high values may lead to incomplete combustion and exhaust smoke if the ignition delay period is too short to allow proper mixing of the fuel and air within the combustion space. On the other hand, cetane ratings below 40 may cause exhaust smoke with increased fuel consumption and loss of power. In general, if the diesel starts and idles satisfactorily and operates smoothly at full power, no gain will be experienced by increasing the cetane rating of the fuel.

Heat of Combustion

The heat of combustion is a measure of energy available from the fuel. Fuels with a high heat of combustion are expected to produce more power than those with lower values. The method of determining the heat value is ASTM D 240-76. A known quantity of the fuel is burned in a bomb calorimeter. The amount of heat liberated raises the temperature of the water bath that surrounds the bomb. This heat of combustion can be expressed as gross (high) and net (low) values. The difference between the two values is equal to the latent energy of vaporization of the water at the test temperature. The higher heat value (HHV), or the gross heat of combustion, was calculated from the calorimeter tests.

Table 1 summarizes the results of the gross heat of combustion for all the samples tested. On a weight basis, sunflower oil with 17,048 BTU per pound contains 12.35 percent less gross heat content than No. 2 diesel. The heat content on a volume basis is different. Sunflower oil has 4.7 percent less gross heat content than No. 2 diesel. From Table 1, the gross heat content of sunflower oil is 131, 270 BTU per gallon and the diesel is 137,519 BTU per gallon.

Sunflower oil has a lower heat of combustion than No. 2 diesel, but its heavier weight makes this difference less when the two figures are compared on a volume basis.

Table 1. Summary of Results for No. 2 D, sfo and 75:25 Blend.

	ASTM for No. 2 D	No. 2 D Tested	75% D 25• sfo	sfo
°API	NS	35.12	31.85	21.77
Cetane No.	40 min.	48	42	31.7
Gross Heat of Comb. BTU/gal	NS	137,519	136,028	131,270
Kin. Vis. mm²/s (100°F)	2.0 min. 4.3 max.	2.40	4.74	34.33

Viscosity

Most of the petroleum fuels as well as the vegetable oils exhibit Newtonian characteristics for which the coefficient of viscosity is a constant. Kinematic viscosity is measured in millimeters squared per second (mm^2/s). ASTM D445 is the test for kinematic and dynamic viscosities of transparent and opaque liquids. It is important to note that viscosity is dependent on temperature. The temperature at which the viscosity determination was made must always be stated.

The results are shown in Table 1. At 100°F the specified temperature for ASTM tests for diesel, sunflower oil is more than viscous than diesel by a factor of 14.

Viscosity affects the performance of injection systems. Low viscosity can result in excessive wear in some injection pumps and power loss due to pump and injector leakage. High viscosity fluids result in excessive pump resistance or filter damage and higher line pressures.

Cloud and Pour Points

When a small sample of vegetable oil is chilled in a glass jar, a cloudy ring appears at the bottom. The temperature at which this phenomenon occurs is called the cloud point and is the start of wax crystal formation in the oil. As the temperature is lowered further, the waxes continue growing throughout the sample until the oil is no longer a fluid but a solid. The temperature at which flow ceases plus 4.5°F is recorded as the pour point.

ASTM D2500-66 is the standard test method for the cloud point while ASTM D97-66 is the standard test for pour point of petroleum oils.

A dry ice and acetone mixture was used to lower the temperature of the samples. Thermocouples were used to record temperatures. Glass jars conforming to ASTM specifications were used. Periodically, jars were removed from the cooling medium and examined for clouding and replaced. The temperatures at which the first signs of clouding appeared was recorded. The samples were further cooled and periodically checked for flow. The temperature at which there was no flow when the jar was held horizontally for five seconds was recorded; 4.5°F was added to this temperature and the total temperature was recorded as the pour point of the fuel.

The average temperatures at which cloud and pour points occurred are presented in Table 2. The difference in temperature at which cloud and pour points occur for the same fuel tested is about 5.4° to 7.2°F. Differences of 7.2 to 10.8°F are common; differences of up to 19.8°F are not uncommon.

The use of sunflower oil as a fuel in unmodified engines would be difficult at temperatures below 16°F. Filter and fuel line clogging will restrict fuel flow as the waxes start to crystallize and grow. The fuel spray will also be affected. If the fuel is to be used at temperatures close to its cloud point, some modifications may become necessary. Agitation of the fuel in the tank and pumping instead of gravity feeding to the injector pump could partly reduce the effects of the reduce flow at cloud point.

Water Content

Water content is determined by heating the fuel under reflux with a water immiscible solvent such as xylene. The condensed solvent and the water are separated in a trap with most of the solvent returning to the still. Water, even in small quantities, is damaging to diesel systems. It causes wear of the precisely machined parts of the injection system, promotes corrosion and may cause filter plugging. No water was present in the samples of sunflower oil, blends and diesel that were tested.

Summary

The test results for the diesel, sunflower oil and a 75 percent diesel:25 percent sunflower oil blend are summarized along with the limiting requirements for No. 2 diesel in Table 1.

If any comparison is made among the fuels, it must be considered that No. 2 diesel is recommended for high speed engines in farm tractors under intermediate to heavy loads at ambient air temperatures above 41°F. When the three fuels are compared, there is a marked difference in the pour point from diesel to sunflower oil. However, when comparing the use of thee two fuels above 41°F, the pour and cloud points can be overlooked, because they occur at temperatues well below this reference temperature.

Table 2. Cloud and pour points of sunflower oil and blends with diesel, °F.

	No. 2 D	75% D 25% sfo	50% D 50% sfo	25% D 75% sfo	100% sfo
Cloud Points, °F	1.4	3.90	8.00	12.51	20.30
Pour Points, °F	-58	2.19	5.85	5.85	16.30

D = No. 2 diesel   sfo = sunflower oil (alkali-refined)
*from Barsic & Humke, 1981   **from U.S. DOE, 1980

The fuel properties that determine a good compression ignition fuel are primarily cetane rating and volatility. They determine the knock characteristics and ease of starting the diesel. Sunflower oil has a relatively low cetane rating compared to the minimum for No. 2 diesel. The importance of this parameter, however, needs to be investigated further as it may not have the same significance for sunflower oil as it would for diesel fuels.

The difference in heat of combustion of the sunflower oil is 4.7 percent lower than No. 2 diesel fuel. Theoretically an engine should consume 4.7 percent more sunflower oil to produce the same amount of work as when using No. 2 diesel fuel.

The higher viscosity of the sunflower oil does not favor its use in unmodified diesel engines. Potential problems with such high viscosity oils are filter and fuel line obstructions, higher injection line pressures and poor atomization.

The fuel properties of diesel fuel-sunflower oil blends were intermediate between the No. 2 diesel, and the vegetable oil. The blends that had proportionally more No. 2 diesel fuel had properties closer to No. 2 diesel fuel. The initial boiling point of the 75:25 blend is just 5.4°F higher than that of No. 2 diesel fuel, so it should vaporize nearly as easily as No. 2 diesel fuel. The cetane rating of this blend is just above 40, the minimum recomended for No. 2 diesel fuel. Its kinematic viscosity is higher than No. 2 diesel fuel at all temperatures. At 100°F, however, it approaches that specified for No. 2 diesel fuel. The gross heat of combustion of this blend is 99 percent of the value for No. 2 diesel fuel. On the basis of this comparison, a 75 percent diesel fuel:25 percent sunflower oil blend should perform very close to No. 2 diesel fuel when burned in the engine under similar conditions.

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Vegetable oil is the favored substitute for diesel fuel. Diesel engines require fuels which self-ignite readily at compression ignition temperatures. This requirement is characterized by a measure of fuel ignition quality called cetane number. The fuel properties of vegetable oils make them a reasonable emergency fuel for farmers. The major technical problem with vegetable oils is their high viscosity and tendency to form residues on combustion. A technology called trans-esterification may solve this problem. The esters have low viscosities and the residue problem may be virtually eliminated.

The problems and potentials of using vegetable oils as an alternative fuel for diesel engines are presented by the various articles in this issue of North Dakota Farm Research. I refer you directly to those articles for information on economics, use in diesel engines, and feeding trials with the meal remaining after the oil has been extracted from the seed.

One of the great benefits of growing plants for oil is the wide variety of species available. One can choose the plant that is best suited for the growing conditions in a particular area. Sunflower is adapted to many parts of the world including the midwest U.S., South Africa, and the Soviet Union. Other vegetable oils may be more suitable for other countries. Besides sunflower, soybean, and peanut, there are more exotic species such as jojoba, guayule, milkweed, eucalyptus, squash, copaiba, malmeleira, babassu nut, and chinese tallow tree.

Vegetable oils have an advantage in that it is easy to extract the oil from them compared to the production of alcohol. All that is required is to squeeze the oil out of the seeds by a simple mechanical operation. However, if vegetable oils are ever to be used as commercial fuels, it will be necessary for them to meet quality standards. These standards will be developed as research continues.

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