Utilization of Alcohol in Spark-Ignition and Diesel Engines
Michigan State University
Cooperative Extension Service
Alan Rotz, Department of Agricultural Engineering
Marcio Cruz, Department of Agricultural Engineering
Robert Wilkinson, Department of Agricultural Engineering
Bill Stout, Department of Agricultural Engineering
July 1980
6 pages

ENERGY FACTS

Cooperative Extension Service
Michigan State University

Extension Bulletin E-1426 July 1980 FILE: 18.826

Utilization of Alcohol

in Spark-Ignition and Diesel Engines

- What is known about alcohol use in engines
- Specific engine modifications
- General trends in engine performance

By Alan Rotz, Marcio Cruz, Robert Wilkinson, and Bill Stout.

Agricultural Engineering Department

Figure 1—Alcohol can be produced from agricultural crops and used as a fuel to produce crops.

As petroleum supplies dwindle at increasing rates, man has begun to develop workable petroleum substitutes. Alcohol is a strong candidate because it can be made from renewable resources. Thus, alcohol would provide a net addition to the energy supply and reduce demands on fossil fuel reserves (Figure 1).

Two common types of alcohol are methanol and ethanol. Methanol, derived from fossil fuel or forest products, is highly toxic. It is commonly used for industrial purposes and as a race car fuel. Ethanol, derived from agricultural crops, is generally used as beverage alcohol. A 100 to 200 proof mixture (50 to 100% alcohol) can be used as engine fuel.

Ethanol holds the most promise for farm operations because it can be produced from a variety of raw agricultural materials. There is much interest in developing fermentation and distillation units for farms because high protein by-products from fermentation can provide feed supplements for farm animals. Surplus crops can be used to produce ethanol and the by-product used as feed.

When alcohol is produced on the farm, a good place to use the fuel is on the farm. By modifying tractor engines (gasoline or diesel-powered) to burn alcohol, farmers can become more self-sufficient in fuel use. Although modifications have been tested in research labs, none have been proven for commercial use. Some risk is involved in implementing this technology. Michigan State University assumes no responsibility for the life or performance of any modified engine.

Use of ethanol as an engine fuel is not new. Henry Ford promoted ethanol usage in his first automobiles. Since then, alcohol fuels have been used when fossil fuels were hard to obtain or when surplus sugar supplies provided a raw material for ethanol production. Alcohols have not become established fuels, however, because petroleum has been abundant and relatively inexpensive until recently.

FUEL COMPARISONS

The chemical makeup and properties of diesel, gasoline and alcohol fuels are very different. A look at these differences shows how alcohols can be used efficiently in engines. Fuel comparisons are outlined in Table 1.

As fuels, ethanol and methanol perform similarly; but there are some differences. Generally, methanol is more corrosive and toxic than ethanol and, therefore, more difficult to handle, store and use in an engine.

Energy Content

A major difference between fuels is their energy content (BTU's[1] of energy per gallon or pound of fuel). Ethanol contains about two-thirds as much energy as gasoline and diesel fuels. This low energy content causes the fuel consumption to normally be higher when alcohol is burned. Thus, a larger quantity of alcohol fuel must be burned when compared to petroleum based fuels to deliver the same amount of work.

Octane Rating

The octane rating also differs between fuels. Octane is a measure of the ability of a fuel to resist detonation (knocking) during combustion. Alcohol's significantly higher octane rating makes it a better fuel than gasoline for spark-ignition engines. Because of the higher octane, alcohol can be used in more efficient, high compression engines. If an engine is properly designed or modified, the gain in fuel efficiency through higher compression offsets a portion of the increase in fuel consumption due to lower energy content.

Cetane Rating

An important property for fuels used in compression-ignition (Diesel) engines is the cetane rating. Cetane is a measure of the ignition delay for the fuel and is inversely related to the octane rating. Due to its high octane rating (the higher the octane rating, the lower the cetane rating), alcohol has a very low cetane rating. The low cetane number makes it inappropriate for direct fueling of Diesel engines; however, it can be used as a supplement to reduce diesel fuel consumption.

Vaporization

In addition, alcohol has a higher heat of vaporization and a lower vapor pressure than gasoline. These two properties combined create problems

[1]One BTU or British Thermal Unit is the amount of energy required to raise one pound of water one degree Fahrenheit.

Table 1—Properties and characteristics of alcohol, diesel and gasoline fuels.

	Gasoline	Diesel	Ethanol	Methanol	Gasohol*	Diesohol**
Source	*Petroleum*	*Petroleum*	*Agricultural products, petroleum*	*Forest products natural gas, coal*	–	–
Formula	C_4-C_{12} mix	C_6-C_{14} mix	C_2H_5OH	CH_3OH	—	—
Specific weight (lb/gal)	6.2	6.9	6.5	6.6	6.2	6.9
Energy content (BTU/gal)	121,000	139,000	84,600	64,600	117,400	133,500
Energy content (BTU/lb)	19,700	19,500	12,800	9,750	19,000	19,000
Pump octane	87-98	20-30	98-102	99-102	90-91	—
Intake air/fuel ratio	14.9	15.0	9.0	6.5	14.0	14.6
Heat of vaporization (BTU/lb)	176	67	396	506	180	—
Boiling point (°F)	31-421	390-640	172	149	31-421	172-640
Vapor pressure (Psia at 100°F)	7.2	—	2.5	4.6	8.2	—
Cetane	—	50	8	3	—	45
Reactions with materials	—	—	Some plastics, rubber, lacquer, paint, epoxy	Some plastics, rubber, copper, brass, terneplate***	—	—

**Defined as 10% anhydrous ethanol and 90% gasoline.*
***Defined at 10% anhydrous ethanol and 90% diesel oil.*
****A lead-tin coated steel used in automobile fuel tanks.*

Sources: (References 1, 2, 10, 12 on page 6) mal consumption of gasoline in gallons per hour (see Figure 2). Along with the high fuel consumption the exhaust emission of hydrocarbons (unburned fuel) will be high.

A solution to this problem is to increase the engine compression ratio to 12:1. An engine could be modified to provide this compression; however, many gasoline engines are not designed to withstand the increased pressures which would occur in the cylinder. A blown head gasket or a more major breakdown may result under heavy engine loads.

Benefits of Straight Alcohol

Some benefits are obtained when a gasoline engine is converted to run on straight alcohol. Alcohol burns relatively cool, so the engine is less likely to overheat, exhaust valves are less likely to burn and lubricating oil may last longer. Lower exhaust temperatures also provide lower emissions of nitrogen oxides, a major pollutant from internal-combustion engines.

Alcohol is a clean-burning fuel. No soot or carbon buildup should occur on engine parts. It may clean old carbon deposits and dissolve varnish and gums which have formed with gasoline usage.

DIESEL CONVERSION

Alcohol can be used in a Diesel engine when; 1) blended with diesel fuel; 2) fed into the intake air for dual fueling; or 3) used as a straight fuel in engines with major modifications. At this time, however, there is essentially no proven commercial technology for using alcohol in Diesel engines.

Blends

Blending alcohol and diesel fuel is possible, but appears impractical. A blend of 90% diesel and 10% anhydrous ethanol has been called diesohol (12). Tests show diesohol lowers engine fuel efficiency due to the lower energy content and very low cetane rating of the added alcohol. Although ethanol and diesel fuel form a homogeneous solution at room temperatures, separation occurs at low temperatures or with the addition of small amounts of water. Another major problem is vapor lock or bubble formation in the injection pump due to the low boiling point of ethanol. Diesohol significantly reduces exhaust smoke.

Dual-Fueling

The most promising method for using alcohol in Diesel engines on the farm is through dual-fueling. Two separate fuel systems are required. Normally, additional equipment is needed to feed the alcohol into the engine. This can be done by aspirating the alcohol into the intake air with a carburetor or with a spray nozzle. Another method uses a separate system to inject the alcohol directly into the cylinder.

The simplest way to get alcohol into the engine is to spray it into the intake air. This procedure is not new technology. A similar process called fumigation has been used to supple-

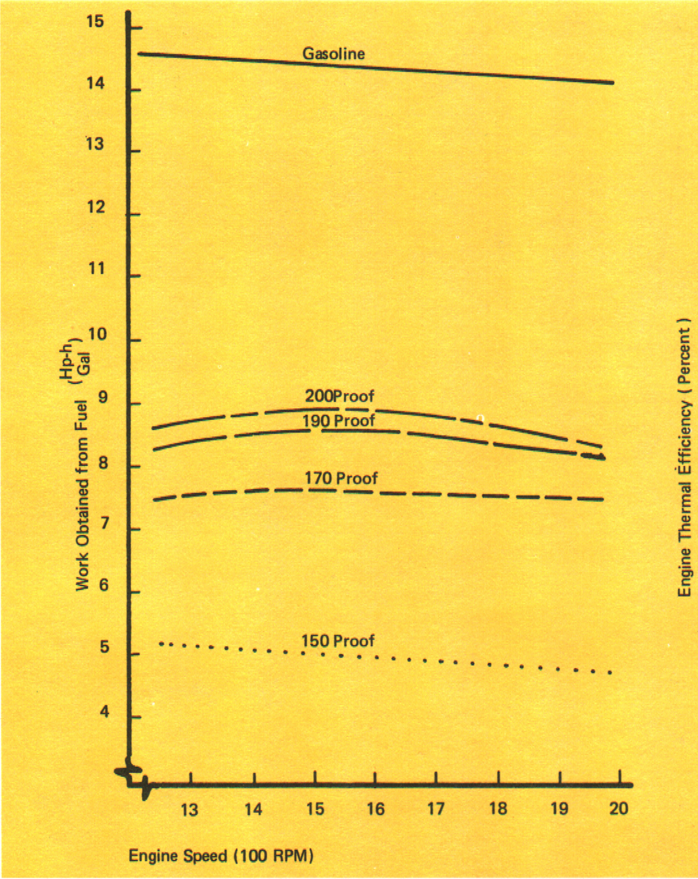


Figure 2—Effect of water content on fuel efficiency for alcohol used in a laboratory engine (5).

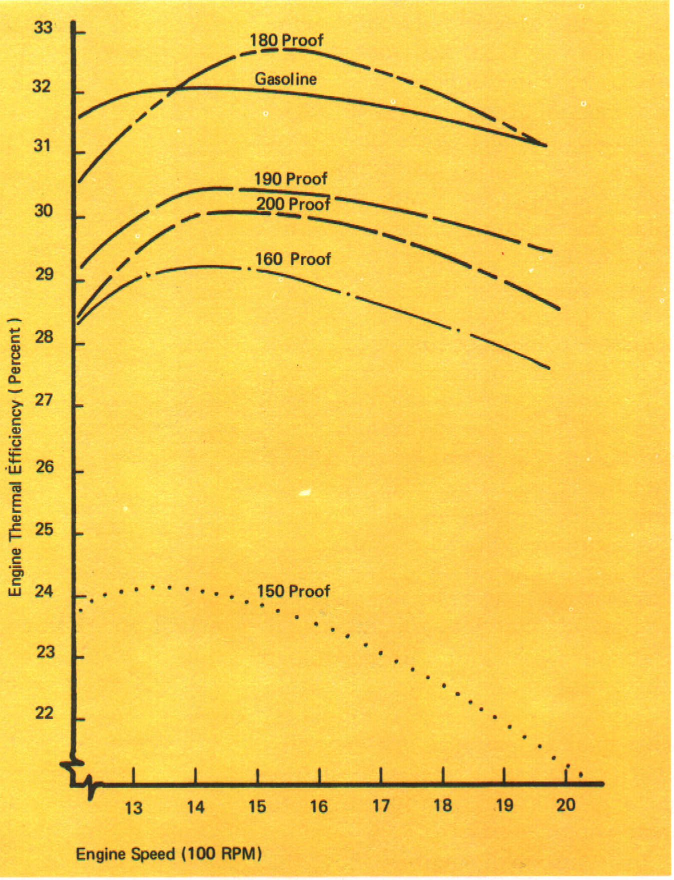


Figure 3—Effect of alcohol water content on engine thermal efficiency for alcohol used in a laboratory engine (5).

ment Diesel engines with liquid petroleum gas. A problem does exist in fumigating with alcohol. Because of the higher heat requirement for vaporizing alcohol, it is difficult to evaporate enough fuel in cool air. This method works better if the intake air is heated through the use of a heat exchanger. A heat exchanger can be added to transfer heat from the exhaust gases or engine coolant to the intake air to aid evaporation of the fuel.

A similar method can be used with a turbocharged Diesel engine. As the intake air is compressed in the turbocharger, its temperature is raised. Alcohol injected into the warm air is easily evaporated and carried into the engine. Because of its high octane rating, alcohol resists preignition when compressed in the cylinder, but it will burn when the diesel fuel ignites. In this way, alcohol can be fed into the engine to displace part of the diesel fuel.

M & W Gear Company has developed a kit to convert a turbocharged Diesel tractor to dual-fueling. It includes a fuel tank, hose and nozzle to deliver the alcohol into the engine. The tank is pressurized with the outlet air from the turbocharger, which forces alcohol from the tank through a hose into the inlet (Figure 4). With this system, the company claims to achieve increased power and reduced diesel fuel consumption. During a test with a 125 horsepower tractor, diesel fuel consumption dropped from 8.5 gallons per hour to 6 gallons per hour with the injection of 100 proof ethanol at the rate of 2 gallons per hour (11).

A problem may be encountered if this type of dual fueling system is built on the farm. Injection of the alcohol into the turbocharger may cause pitting of the turbine blades. This will lower turbine efficiency and eventually destroy the turbocharger.

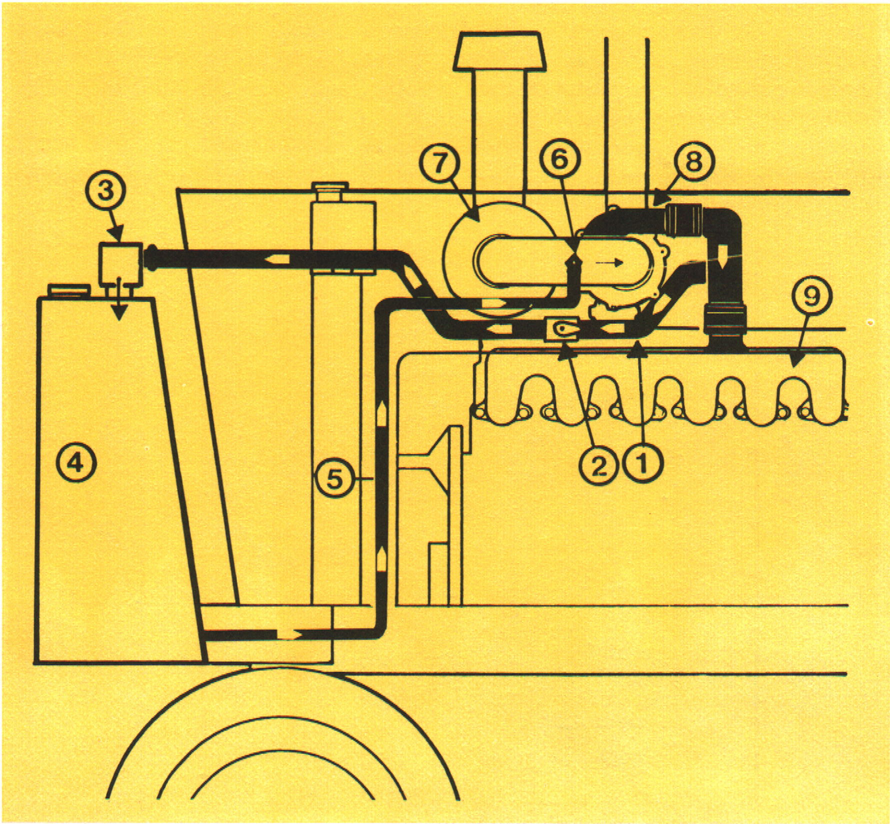
A carburetor may also be used to introduce alcohol into the intake air. Tests have been run with an updraft carburetor mounted on the intake manifold of a small Diesel engine (4). This method performs better with a heat exchanger to transfer heat from the exhaust gas to the inlet air to promote vaporization.

Tests on small engines show that adding alcohol increases torque. Thermal efficiency decreases with added alcohol at low torque levels, but increases at high torque levels. Exhaust temperatures decrease with alcohol use because alcohol is a cooler burning fuel. Carbon monoxide and unburned hydrocarbons are generally greater when alcohol is used than when diesel fuel alone is burned. Nitrogen oxides, however, are reported to be reduced with the cooler burning alcohol.

The ratio of alcohol and diesel fuel consumption varies with engine load. At 50% of maximum load, alcohol can supply about 70% of the fuel energy. On lower and higher loads, the engine will not tolerate as much alcohol. Under typical use, alcohol can replace about half of the diesel fuel in this type of dual-fueled engine (4).

An engine with separate injection systems has also been tested (2). A special lubricated pump and injectors are installed to inject the alcohol. This method of dual fueling is feasible but requires major engine modifications which reduce its usefulness for an on-farm conversion. Alcohol is injected into the cylinder following the diesel fuel. The diesel fuel ignites under compression, causing the entire charge to burn. Engine efficiency resembles that obtained with straight diesel. The injected alcohol can displace up to 70% of the diesel fuel. Exhaust smoke and temperature are reduced.

There are no abnormal problems in starting dual-fueled engines. The engine can be started on diesel fuel and alcohol added after it is warmed up.



1. Pressure line
2. Shut-off valve
3. Water/air separater
4. Storage tank
5. Alcohol feed line
6. Check valve
7. Turbocharger inlet
8. Turbocharger
9. Intake manifold

Figure 4—Diagram of alcohol injection on a turbocharged diesel tractor, M & W Gear Company (11).

in starting cold engines on alcohol. Because of the higher heat requirement for evaporating alcohol, the intake air must be relatively warm to provide heat for vaporization. To start a carbureted engine on alcohol, the intake air must be 50°F or above. For smooth, efficient operation in cold weather, the intake air should be raised to nearly 200°F.

Corrosion

Alcohols react with certain materials which are compatible with petroleum fuels. Alcohol is a solvent which breaks down some types of plastics and rubbers. Certain metals also corrode more readily when exposed to alcohol. Generally, ethanol is not as corrosive as methanol. Neither of the forms are as corrosive when maintained relatively free of additives because some additives chemically react with alcohol to increase corrosion. A common additive required in industrial ethanol is a denaturant. The best denaturant for fuel grade ethanol is probably methanol.

GASOLINE CONVERSION

Alcohol fuels can be used in gasoline engines as alcohol-gasoline blends or as straight alcohol fuel.

Blends

A common blend, gasohol, consists of 90% unleaded gasoline and 10% ethanol. In this blend, alcohol replaces the tetraethyl lead additive in gasoline used to increase its octane rating. Gasohol has a lower energy content per unit volume than gasoline, but does not result in a significant decrease in fuel efficiency (miles per gallon).

Blends have the advantage of being used in unmodified engines, but they present problems in mixing on the farm. To obtain a uniform solution of alcohol and gasoline, near anhydrous alcohol (little water, about 200 proof) should be used in the blend. Small amounts of water cause the solution to separate into an upper layer of gasoline and a lower layer of water and most of the alcohol.

Alcohol produced on the farm would normally have a maximum proof of 190 (5% water). To remove the remaining water, more sophisticated equipment is needed which requires more capital and greater energy inputs during production. **For these reasons, alcohol blending does not appear feasible for on-farm production.**

Straight Alcohol

Straight alcohol of 140 to 200 proof can be burned in gasoline engines with minor modifications (3, 5, 7, 8, 9, 10).[2] The metering jets in the carburetor must be enlarged. Alcohol has a lower energy content and, therefore, requires a lower air/fuel ratio for the intake mixture. When burning ethanol, the cross-sectional area of the jets should be increased about 1.5 times their original size to meter proportionally more fuel into the intake air. All jets, therefore, must be replaced or drilled to a new diameter of 1.27 times the original diameter. After this modification is made, the engine will no longer operate on gasoline.

All incompatible parts, some plastics and rubbers must be removed from the fuel system. Alcohol will slowly dissolve these materials, causing fuel contamination and damaged parts.

Ignition timing may be shifted slightly when alcohol is burned. The change will depend on the engine used and previous adjustments. Some report a small delay; others report an advance in ignition timing. In general, the higher octane fuel should tolerate an advance in the timing, which will allow a small increase in engine thermal efficiency.

With these changes an engine should start and perform satisfactorily on a warm summer day. Benefits obtained with the conversion include slightly increased engine thermal efficiency and sometimes increased torque and power. The increases are a function of fuel water content (see Figures 2 and 3). An increase in thermal efficiency means that more energy or work is obtained from the engine for each BTU of fuel energy consumed. But the fuel still has a lower energy content per gallon, resulting in higher fuel consumption.

Cold Engine Starts

This form of conversion for a gasoline engine is relatively simple and inexpensive, but it presents problems with cold engine starts. As stated previously, the intake air must be about 50°F or above. Special equipment is needed to start engines at lower temperatures. A torch or electric-resistance heating element may be used to heat incoming air, but this is not recommended because alcohol fuel is highly volatile. Fire may occur when alcohol is exposed to open flame or high temperatures. A more appropriate solution may be to use a special starting fuel such as gasoline or propane. By adding a small propane tank or gasoline injection device, starter fuel can be released into the intake manifold to aid cold weather starting.

Because alcohol has a higher heat of vaporization and a higher boiling point, the intake air must still be heated after the engine is started for smooth, efficient operation. To provide this heat, a heat exchanger is needed to transfer heat from the exhaust gases or the engine coolant to the intake air. Specially designed intake manifolds are available with a water jacket to allow circulation of the engine coolant through the manifold. Another possible method is to wrap copper tubing tightly around the intake manifold. With any of the methods, after engine warm-up, the incoming air can be warmed to the necessary 200°F.

Heating the intake air may cause another problem. The expanded hot air entering the engine is less dense reducing the volumetric efficiency of the engine. The result is a slight decrease in the maximum available power.

Compression Ratios

When a gasoline engine is converted as described previously, one major problem still exists. Alcohol is a high quality (high octane) fuel which burns most efficiently under high compression. When used in an engine designed for gasoline (compression ratio of 6:1 to 8:1), the thermal efficiency is lower than optimum for alcohol fuel; therefore, fuel consumption is higher than necessary. Fuel consumption may be as much as 1.5 times the nor-

---

[2]Numbers in parentheses refer to References listed on page 6.

TRUE ALCOHOL ENGINE

An engine can be built which best utilizes the unique properties of alcohol. This engine uses a compression ratio of about 12:1, fuel injection and spark-ignition. Alcohol is injected at high pressure directly into the cylinders using a lubricated fuel pump and specially lubricated injectors. The fuel evaporates quickly in the heated air inside the cylinder, and a spark plug is used to ignite the mixture. This arrangement is sometimes referred to as the Brandt System (8).

In 1941, the National Experiment Station of France tested a four-cylinder engine modified to the Brandt System. The thermal efficiency was very high (about 42% compared with 30% with gasoline). Because of the high efficiency, fuel consumption was nearly the same as with gasoline, even though the energy content of alcohol is 30% less than that of gasoline.

With major modifications, a Diesel engine can be converted to the Brandt System. The amount of modification involved reduces its usefulness for on-farm conversion. Required changes are outlined as follows (8):

1. The engine head must be drilled and fitted with sleeves through the water jacket to install spark plugs.
2. A flat steel plate must be machined and fitted between the block and head to decrease the compression ratio to 12:1.
3. A distributor or other ignition timing device must be added.
4. The fuel pump and injectors must be replaced with specially lubricated units suitable for use with alcohol.

This engine has several advantages. The alcohol burns cooler, reducing pollutants and mechanical problems. Cold starting problems are eliminated. Since alcohol is injected directly into the hot compressed air of the cylinder, the engine starts and runs smooth regardless of outside temperatures.

Several major automobile manufacturers are developing automotive engines for use with straight alcohol in Brazil. Their design will likely compare closely with the engine design described above with high compression, spark-ignition and possible fuel injection. One manufacturer has recently delivered several tractors to Brazil which burn straight alcohol. These tractors contain spark-ignition engines with a compression of about 12:1. Fuel is delivered through carburetion and special equipment is installed for heating the intake air (6).

SUMMARY

Ethanol is a suitable alternative for engine fuel. Straight alcohol can be burned in a gasoline engine by enlarging the carburetor jets, adding heat to the intake air, and adding equipment to facilitate cold engine start. Alcohol can be used more efficiently in a spark-ignition engine by increasing the compression ratio to 12:1. Many spark-ignition engines, however, are not designed to withstand this high compression in the cylinders.

Diesel engines can be modified to burn alcohol through dual-fueling. Alcohol can be sprayed or aspirated into the intake air or directly injected into the cylinder to partially fulfill the engine fuel requirement. Through dual-fueling, alcohol can replace about half of the diesel fuel requirement.

The true alcohol engine requires about a 12:1 compression ratio, a fuel injection system, and spark-ignition. With this type of engine, straight alcohol can be burned to provide smooth starting and operation in all weather. A Diesel engine can be converted to a true alcohol engine through major modifications. Spark plugs must be installed along with a spark timing device. The compression must be decreased and the fuel-injection system replaced with a lubricated unit suitable for use with alcohol.

Alcohol fuels provide several benefits. They burn at a cooler temperature, improving the life of motor oil and possibly reducing engine wear. They are clean-burning, which reduces soot and carbon buildup. A well-designed, well-adjusted engine may substantially reduce many exhaust emissions.

Most important, alcohol can be produced from renewable resources grown on our own farms.

REFERENCES

Other publications in this series are:
—*Making Ethanol for Fuel on the Farm, (AEIS 421) (Dept. of Agr. Engineering)*
—*Feeding Distiller's Grains to Livestock, (AEIS 429) (Dept. of Agr. Engineering)*

1. American Petroleum Institute, 1976. Alcohols: A technical assessment of their application as fuels. Pub. No. 4261, American Petroleum Inst.
2. Berg, P.S., E. Holmer and B.I. Betilsson, 1979. The utilization of different fuels in a Diesel engine with two separate injection systems. Proceedings of the Third International Symposium on Alcohol Fuels, Volume II, May 8, Asilomar, Calif.
3. Chui, G.K., R.D. Anderson, R.E. Baker and F.B.P. Pinto, 1979. Brazilian vehicle calibration for ethanol fuels. Proceedings of the Third International Symposium on Alcohol Fuels, Volume II, May 8, Asilomar, Calif.
4. Cruz, J.M., W.J. Chancellor and J.R. Goss, 1979. Dual-fueling a Diesel engine with carbureted alcohol. Proceedings of the Third International Symposium on Alcohol Fuels, Volume II, May 8, Asilomar, Calif.
5. Deardorff, T., 1979. Operation of a spark-ignition engine with a range of ethanol and water mixtures. Unpub. report. Agr. Engin. Dept., Iowa State Univ., Ames.
6. Gratch, S., and D. McLean of Ford Tractor Operations, 1980. Alcohol fuels and their use in spark-ignition or Diesel engines. Oral report, Farmers' Week, March 17–21. Michigan State University.
7. Hauck, D. and V. Hofman, 1979. Alternate energy sources. Unpublished report. Agr. Engin. Dept., North Dakota State Univ., Fargo.
8. Kirik, M. 1978. The possibilities of alcohol use as an alternate fuel in farm machinery. Paper, Northeastern Ontario Agri. Conference. Feb. 28, New Liskeard, Ontario.
9. Menrad, H., 1979. A motor vehicle powerplant for ethanol and methanol operation. Proceedings of the Third International Symposium on alcohol fuels, Volume II, May 8, Asilomar, Calif.
10. Mingle, J.G., 1979. Converting your car to run on alcohol fuels, Bulletin No. 56, Engin. Exp. Sta., Oregon State Univ., Corvallis.
11. M&W Gear Co., 1979. M&W Aquahol Injection. Promotional material. M&W Gear, Route 47 South, Gibson City, Ill.
12. Wrage, K.E., and C.E. Goering, 1979. Technical feasibility of diesohol. ASAE Paper No. 7901052, Amer. Soc. Agr. Engin., St. Joseph, Mich.

This information is for educational purposes only. Reference to commercial products or trade names does not imply discrimination or indorsement by the Cooperative Extension Service. Cooperative Extension Service Programs are open to all without regard to race, color, national origin, or sex. Issued in furtherance of cooperative extension work in agriculture and home economics, acts of May 8, and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Gordon E. Guyer, Director, Cooperative Extension Service, Michigan State University, E. Lansing, MI 48824. 1P-10M-7:80. Price 25 cents.