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The Use of Alcohol in Farming Applications

Alternative Fuels Utilization Program

November 1980

Prepared for:

U.S. Department of Energy
Assistant Secretary for Conservation
and Renewable Energy
Office of Transportation Programs
Under Contract No. AC02-79CS-50025
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FORWARD

The increasing demand for distillate fuels in the United States over the past few years, plus the potential for disruption of imported petroleum supplies, currently provides a growing incentive to find suitable nonpetroleum-based alternatives. While certain distillates, such as commercial aviation jet fuel, are not amenable to easy replacement, others such as diesel fuel can tolerate a wider variation of properties without serious operational consequences and are therefore subject to supplementation. The use of alcohol with diesel fuel has been investigated as a means of extending diesel fuel supplies. This possibility is of extreme importance to U.S. farming communities since diesel engines are used extensively in farm machinery and equipment, and since ethanol can be produced locally from agricultural products and/or wastes. The ability to use ethanol in diesel-powered farm equipment could provide the means for increasing the near-term fuels self-sufficiency of the American farmer. In the longer term, the potential availability of methanol (from coal) in large quantities could serve to further decrease the dependency on diesel fuel.

This document gives two separate overviews of the use of alcohols in farm equipment. Part I, The Use of Alcohol in Farm Diesels was prepared by G. L. Borman; D. E. Foster; P. S. Myers; and O. A. Uyehara of the University of Wisconsin under DOE contract DE-AC02-79CS-50025. Part I of this document compares alcohol with No. 1 and No. 2 diesel fuels and describes several techniques for using alcohol in farm diesels. Part II, Use of Aqueous Ethanol as Farm Vehicle Fuel was prepared by P. W. McCallum and T. J. Timbario of Mueller Associates, Inc., under DOE contract DE-AC05-79CS-56051. Part II of this document discusses the use of aqueous ethanol in diesel engines, spark ignition engines and provides some information on safety and fuel handling of both methanol and ethanol. This document is not intended as a guide for converting equipment to utilize alcohol, but rather to provide information such that the reader can gain insight on the advantages and disadvantages of using alcohol in existing engines currently used in farming applications.

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PART I
THE USE OF ALCOHOL IN FARM DIESELS

THE USE OF ALCOHOL IN FARM DIESELS

Introduction

Farmers are developing a strong interest in alcohol as a fuel. On the one hand, many farmers claim that a large-scale gasohol program such as the one proposed by President Carter will create new markets, and put the idle cropland into production, or utilize waste materials such as whey. On the other hand, some farmers are predicting that on-farm alcohol stills will provide a readily available and comparatively inexpensive fuel for farm diesel engines. Whatever your point of view, there are considerable risks in alcohol production and utilization. This paper will evaluate one aspect of alcohol utilization: its use as a fuel in farm diesels.

1. Considering all of the energy required to extract and prepare alcohol as a fuel, is there a net energy gain? Many answers are possible depending on how one makes the energy balance, the size and design of the still and the utilization of by products. Consider the conversion of corn, if one counts all of the energy and fertilizer required to plant, till and harvest the crop, plus all of the energy required to convert the crop to alcohol and subtracts off the useful energy of the by products and alcohol the result is close to zero. Some authorities claim there is a net energy loss for alcohol from grain - others claim there is a gain. There seems to be general agreement that, if collection costs are not too high, there is a net energy gain if waste materials such as corn cobs are used as the boiler fuel.
2. Ignoring the question of energy gain or loss, is the final form - alcohol in our case - more useful than the form of used to produce the alcohol? If some portion of the energy used to produce the alcohol is petroleum, the alcohol is equally but not more useful than that portion. If some portion of the energy used is coal, solar, nuclear, waste biomass, etc., alcohol is a more useful form than that portion.

3. Is it economically competitive with other fuels? Today, ethyl alcohol which has about two thirds of the energy content of gasoline sells wholesale for more than \$1.50 per gallon. This should be compared to a wholesale price of close to one dollar per gallon for gasoline. Note that on an equal energy basis the alcohol wholesale cost is currently 2.25 times that of gasoline.
4. Are there availability, political or military reasons to use this particular fuel? If a farmer or farmers coop can produce and store alcohol, such availability may be a significant factor since the timing of planting and harvesting is crucial.

Since a majority of the horsepower-hours on farms is supplied by the diesel engine, it is important to evaluate the usefulness of alcohol as a fuel in diesel engines. The critical distinction is that while alcohol or gasohol can be used in a spark-ignition engine with little or no engine modification, there is no currently available technology--either by retrofitting or new design--which will permit the use of large percentages of alcohol in diesel engines.

Nevertheless, as the availability of diesel fuel decreases, it may become necessary to use alcohol as an emergency fuel to extend the supply of fuel for farming operations. Ways are therefore being explored to retrofit existing diesel engines and to develop new diesels which can utilize a wider range of fuels, including alcohol.

Although there are about a half-dozen potential methods for the use of alcohol in diesels, either by retrofitting or new design,, none are totally acceptable or adequately proven methods. Thus, although development work is going on and one system can be purchased, a proven commercially available system does not exist. The advantages and disadvantages of the presently available options will be briefly discussed in the following evaluation.

Comparison of Alcohol With No. 1 and No. 2 Diesel Fuels

Two kinds of alcohol are usually considered for fuel--methyl (methanol) and ethyl (ethanol) alcohol. The ethyl alcohol molecule is heavier than the

methyl alcohol molecule - in general, the heavier the alcohol molecule the more its physical characteristics resemble those of gasoline or fuel oil. Table I gives a comparison of the physical characteristics of pure methyl and pure ethyl alcohol with those of diesel fuel oils No. 1 and No. 2 and gasoline. Simple stills produce 100 proof (50% water by volume) alcohol and more complex stills can produce up to 190 proof. Addition of water of course proportionally reduces the energy content of the mixture.

It can be seen from Table I that both absolute alcohols have considerably less energy per gallon than either gasoline or diesel fuel. This is an important fact since diesel engines convert essentially the same fraction of energy in the fuel to useful work, and fuel is priced on a per gallon basis. In other words, since ethanol only has about two-thirds of the energy per gallon of diesel fuel (Table I) its price will have to be about two-thirds of that of diesel fuel if the fuel cost for doing a given amount of work is to be the same between the two fuels. Also, at maximum rated power the injector puts the maximum volume of fuel it can into the engine cylinder per combustion cycle. If the same volume of alcohol has only two-thirds as much energy as diesel fuel you will only get about two-thirds as much power from the engine unless you adjust the injector volume (little adjustment is possible), put in new, larger injectors and nozzles, or get the alcohol into the cylinder in some other way - by mixing it with the intake air, for example.

It takes several times more energy to change a gallon of alcohol from a liquid to a vapor as it does to change a gallon of gasoline from a liquid to a vapor. The energy required is called the latent heat of vaporization and is shown in Table I. This extra cooling effect may be helpful if extra cooling is needed, or harmful if the air into which the fuel is being introduced is already too cold.

Because alcohol has very little lubricity, some sort of lubricant must be added to lubricate the injectors if the existing diesel injectors are used. If a lubricant is not added, damage to the expensive injection system is almost certain. There are some injector designs that do not depend on the fuel for lubrication--they would, of course, work satisfactorily without the addition of a lubricant to the alcohol.

Table I shows that alcohol has an estimated cetane (the equivalent to octane in gasoline) number of around zero as compared to 40-45 for diesel fuel. In the diesel engine only air is compressed during compression, with the fuel being injected into the hot, compressed air shortly before the piston reaches the top of its stroke. In spite of the high temperature and pressure of the air there is a short time delay (around one-thousandth of a second) before the fuel begins to burn. The length of delay varies between fuels so the parameter of cetane number is used to characterize the ignition delay of a given fuel. A fuel with a low cetane number has a long ignition delay; a high cetane fuel has a short delay. This ignition delay is of interest under starting and low inlet manifold temperature conditions since it gets rapidly longer as temperature decreases. If it is too long the engine will not start at all; excessive ignition delays also cause harsh combustion, high ring and cylinder liner wear and piston erosion.

There can also be a material compatibility problem in diesel engines, especially when using pure alcohol. For example, in engines not specifically designed for alcohol use, some of the rubber-like materials used in the fuel system may become soft when used with pure alcohol. Some aluminum alloys may react with alcohol, and some coatings which are put on the inside of steel fuel tanks to keep them from rusting may be removed by pure alcohol. The lower the percentage of alcohol, the less severe the problem.

TECHNIQUES FOR ALCOHOL USE IN FARM DIESELS

Conversion From Diesel to Spark Ignition

Because ethanol is a high octane number fuel it is best suited to use in spark ignition engines. The most obvious way to use this type of alcohol fuel in diesel engines would therefore be to convert existing diesels to spark ignition. This might be done by changing the head to lower the compression ratio, replacing the fuel injectors with spark plugs and introducing the fuel through the intake either by carburetion or direct injection into the manifold.

Such changes are expensive, however, and not well suited to retrofitting, particularly for turbocharged engines. If the compression ratio

is kept high, for good efficiency, the engine will not be very flexible since it will demand a high octane number fuel. If a carburetor is used, adjustment of the jets will be necessary when changing from pure alcohol to fuels with higher energy densities such as gasoline. Although injection of alcohol can present a problem due to lack of lubricity, the problem is apt to be minimal for low-pressure injection systems such as used to inject fuel into the manifold.

A less complicated method of changing to spark ignition might be achieved by injecting the alcohol into the cylinder as a high pressure spray. The ignition problem could be overcome by providing a source of ignition such as a spark plug or a hot surface igniter. This concept is not new, the first commercial spark-ignited diesel is attributed to Hesselman and a version has been manufactured by Volvo. Such an engine could be quite flexible for farm diesels if the ignition source could be made to perform well with low cetane number diesel fuels, as well as alcohol.

The problems which arise with this type of system are fuel-wetting of the spark plug (which causes misfire, typically during cold starting) and short spark plug life. Recently other means of ignition, such as using a hot surface igniter have shown promise, but they have not yet been commercially developed. Thus, the concept of creating an ignition source in the cylinder of a diesel engine remains a promising but as yet undeveloped means of providing a multifuel engine.

Another method of ignition of low cetane fuels is to provide for a pilot injection of diesel fuel. This method requires an engine with a special head with two injectors, and is thus expensive. This would be a moderately flexible engine, but its operation may require use of all diesel fuel during warmup and a high cetane fuel for the pilot ignition. A few laboratory engines of this type have been run but the cost factor will probably restrain commercial production.

Fumigation

The concept of using pilot injection to ignite low cetane number fuel (alcohol) is expensive because of the extra injector system. A similar method can be used, however, if the low cetane number fuel is introduced

into the cylinder through the intake valve as a lean fuel-air mixture. The alcohol would be ignited by use of diesel fuel injected directly into the cylinder. Clearly, this method, like that of pilot injection, requires the use of some diesel fuel. This method has its limitations, however, because of either preignition (if the manifold temperature is too high) or poor ignition (if the manifold temperature is too low). Low manifold temperatures may also lead to poor fuel distribution between cylinders because of the large amount of energy needed to vaporize alcohol. For turbocharged engines, introduction of the alcohol upstream of the compressor should provide good vaporization and mixing. But this method, too, is not without problems. Alcohol droplets impinging on the impeller of the compressor may cause severe impeller erosion and transient performance of fumigated turbocharged engines may be poor.

Fumigation is attractive as a means of retrofitting at reasonable cost. Although such systems use alcohol only at higher loads, they do provide a means of alcohol utilization as well as the flexibility of operating the engine normally with pure diesel fuel. One such system design has been presented by the M & W Gear Company and is shown in Fig. 1. The engine can be operated with all diesel fuel or with fumigation at higher loads. In addition to the possible erosion damage to the turbocharger, the operator must be aware of the dangers of overfueling (due to alcohol addition) which could harm the engine and/or the transmission. Adjusting the diesel fuel injection pump to limit power output to manufacturer's specifications when alcohol is added can avoid this problem and is recommended by the M & W Gear Company. Unfortunately the system does not provide an instrumentation system which would measure overfueling conditions and warn the operator.

Combining Alcohol and Diesel Fuel

The use of gasohol (a mixture of about 10% ethanol and gasoline) in automotive spark-ignited engines is well known, but a similar approach to diesels is not as viable because diesel fuel and alcohol do not mix unless the water content of the alcohol is less than 0.5 percent. If the two fuels are to be combined for use in a diesel engine additional hardware is necessary to cause mixing.

Small amounts of alcohol may be introduced into the injector manifold (gallery). This method severely limits the amount of alcohol used and gives considerable cycle-by-cycle variability and poor performance under transient conditions. Introduction of the alcohol also lowers the cetane number which in turn causes poor combustion and possible increased engine wear.

Another means of mixing the two fuels is to run them through an emulsifier. This device breaks the alcohol into very tiny droplets so that the fuel at the outlet is a mixture of diesel fuel and alcohol droplets. Such emulsions can be made and stored but the fuels eventually separate again so that shelf life is very short - at best a few days. Storage also increases the chances of water pickup from the atmosphere. These problems of storage and water pickup may be prevented by installing the emulsifier in line with the injector. The system is complicated by the fact that a large portion of the fuel must be recirculated; thus a separate pump and fuel cooler must be provided along with the emulsifier unit.

As with gallery mixing, the addition of emulsified alcohol lowers the cetane number and thus limits the amount of alcohol used to a small percentage of the total fuel used. The injector must be properly sized to accommodate the lower-energy emulsion fuel, and some flexibility is lost. The use of emulsified fuels is currently best suited to steady-state, full-load conditions; the design of systems suitable for field conditions requires further development.

Cetane Improvers

Addition of some chemical compounds to low-cetane fuels such as an alcohol can increase the cetane number and thus make direct use of the improved fuel possible. The cetane improvers tested thus far require large amounts (20% or more) to be added to the alcohol. Unfortunately these cetane improvers are very expensive. Running with marginal amounts of cetane improver causes cold-starting problems and increased ring-liner wear. While inlet air temperature control and other design modifications may help this situation, the basic problems of cost and availability of cetane improvers remain. Even if much better cetane improvers are found, the alcohol fuel will still have a lower energy than diesel fuel, so that

switching from diesel fuel to cetane-improved-alcohol will lower the engine power unless the injectors are changed when the switch is made.

CONCLUSIONS

The results of our study show that there are not yet any practical, inexpensive methods for using alcohol as a diesel fuel. Cetane improver additives, injector gallery mixing and refinery-produced emulsions are currently not viable techniques. Methods such as spark or hot-surface ignition and pilot injection are expensive and probably limited to new engine designs. Thus, only fumigation and on-board emulsification are serious candidates for current use. Either method, if perfected, could be used to retrofit existing engines and could provide a choice of fuel. However, both methods require two fuel systems and do not allow use of 100% alcohol. Both methods must be used with caution since they could cause engine damage.

TABLE I
SELECTED LIQUID FUEL CHARACTERISTICS

CHARACTERISTIC	FUEL				
	Methyl Alcohol (Methanol)	Ethyl Alcohol (Ethanol)	Gasoline	Diesel No. 1	Diesel No. 2
Source	Natural Gas, Coal, Wood, Solid Waste	Agricultural Products Petroleum	Crude Oil		
Energy Content in BTU Per Gallon	56,560	75,670	115,500 (average)	126,500 (average)	129,000 (average)
Energy in BTU to Vaporize one Gallon	3,340	2,378	900 (average)	750 (average)	
Weight, Pounds Per Gallon	6.59	6.59	5.8-6.5	6.8-7.2	
Cetane Number	2-10	10-15	5-20	42-46	40-45
Lubricity	Poor	Poor	Poor	Good	Good

AQUAHOL INJECTION SYSTEM

1 Pressure Line	7 Air Cleaner
2 Shut Off Valve	8 Turbocharger
3 Liquid/Air Separator	9 Intake Manifold
4 Aquahol Storage Tank	
5 Aquahol Feed Line	
6 Check Valve and Orifice	

PART II

USE OF AQUEOUS ETHANOL AS FARM VEHICLE FUEL

USE OF AQUEOUS ETHANOL
AS FARM VEHICLE FUEL

Currently, there is considerable interest in the fuel uses of fermentation ethanol to extend petroleum supplies. Interest is especially strong in farming areas since fuel-grade ethanol could be produced and used on the farm. Depending on the purity and quality of the ethanol produced, there are several options for its use as fuel. It can be used as heating fuel for such applications as crop drying where it might substitute for propane or liquefied petroleum gas (LPG). Other stationary heating applications may also be candidates for the use of alcohol, with appropriate equipment modification and safety precautions. However, the use of ethanol in internal combustion (IC) engines is the topic that will be treated here, to the exclusion of direct heating applications.

Fermentation ethanol can be used in IC engines of both the spark ignition (SI) and diesel types and in the turbocharged and naturally aspirated versions of either. Stationary engines, such as those used to operate irrigation pumps or electric generators, may be easier to adapt to alcohol fuel usage due to their operation at essentially constant speed and load. Mobile engines (cars, trucks, and heavy equipment such as tractors) can also use ethanol fuels, although the modification necessary to adapt such engines may be more involved since they must operate flexibly over wide ranges of speed and load.

Several types of alcohol fuels can be produced. By now, Gasohol is familiar to most Americans. Gasohol is a blend of ethanol (10%) and unleaded gasoline (90%). Other blend proportions can also be used, requiring varying degrees of engine modification. Ethanol can also be mixed with leaded gasoline. Provided it is water-free (anhydrous), ethanol will also mix with diesel fuel, although "dieselhol" is much less well-known and somewhat less practical than ethanol-gasoline blends. Ethanol can also be used straight or "neat" in SI engines (not in diesels), although starting an engine on ethanol when it is "overnight"

cold may require a small supplement of a more volatile fuel (e.g., gasoline).

In those applications where ethanol is produced and used in a small-scale, private operation such as a farm, it would be particularly advantageous if low-proof, aqueous (water-containing) ethanol could be used since this product is considerably easier to make, requiring less investment and effort than anhydrous (water-free) ethanol.

A significant water content, however, places practical limits upon the methods by which ethanol can be used as an engine fuel and restrictions upon the applications which are candidates for alcohol utilization. A water content of as low as 1 percent (198° proof ethanol or less) may preclude direct blending with petroleum products because under many conditions, an alcohol-water phase separates from a predominantly petroleum phase. The resulting two-phase "mixture" does not allow normal engine operation. Thus, for 140 to 190° proof fuel ethanol, the practical methods of utilization are effectively reduced to dual-fuel injection or fumigation (carburetion or injection into the intake air stream) and perhaps on-board mechanical emulsification with diesel fuel for diesel-engine vehicles and to straight fuel use or supplementary alcohol/water injection for SI-engine vehicles.

Aqueous ethanol is a low-energy, high latent heat fuel relative to petroleum fuels. Thus, when it is used as a straight fuel in SI-engine vehicles, range between refuelings is limited severely by the lower energy content of a given number of gallons of alcohol fuel compared to gasoline. Further, SI-engine vehicles typically undergo some degradation of cold-startability and warm-up driveability due to the much-reduced volatility and increased evaporative heat requirement of aqueous ethanol relative to gasoline. To overcome these operational difficulties, a small supplementary gasoline or LPG starting fuel system can be used.

When aqueous ethanol is used as an internal coolant, injected into the engine's intake manifold to suppress knock, it is usually

highly effective, but any resultant petroleum savings are insignificant.

Since specialized farm vehicles such as tractors have been heavily dieselized in recent years (90-95 percent of current production is diesel-powered), these applications offer greater petroleum conservation potential. A substantial proportion of these power plants in the higher horsepower ranges are turbocharged and this is an aid to their utilization of ethanol/water mixtures.

It should be kept in mind that the aqueous ethanol which is discussed herein is the product of limited distillation severity and not a deliberately diluted ethanol. The distillation required to produce 140-190° proof ethanol is less energy-intensive and demands less expensive technology than that required to remove the last few percent of water. Thus, the low-proof product is expected to be more representative of typical farm still output.

Further, it is worth mentioning that the vast majority of research and development work done with alcohol fuels has employed chemical reagent grade alcohols used straight or in gasoline blends. The use of aqueous alcohols has received much less attention. Accordingly, the state of technical knowledge is a great deal less advanced and there has been notably less information reported by recognized researchers. More work is needed in this area and some, fortunately, is underway.

A summary is presented below of the possibilities, risks, and limitations of employing aqueous ethanol in IC-engine farm vehicles.

I. NATURALLY ASPIRATED AND TURBOCHARGED DIESEL ENGINES

A. Use of Low-Proof Ethanol as Fumigant (Secondary Fuel Carbureted or Injected into Engine's Intake Air Stream)

1. Materials compatibility:

- a. Potentially among the most serious problem(s).
- b. Relatively little specific, detailed information is available.

- c. Aqueous ethanol may be more benign than neat (straight) or gasoline-blended ethanol to some materials. To others (such as magnesium alloys), it appears to be more aggressive.
 - d. Close coordination with component suppliers is necessary - materials substitution is often difficult due to limited alternative materials availability.
 - e. Non-metallic materials (synthetic elastomers, plastics, etc.) may be most strongly affected by ethanol. Resistant materials are available but may not always be available in the required form (e.g., fuel hose).
 - f. Finding solutions to specific materials problems is largely a do-it-yourself proposition.
2. Oil dilution (with water/ethanol):
- a. Positive crankcase ventilation (PCV) very desirable. It is present on all vehicles 1968 and newer and should be retained.
 - b. Adequate mixture heating also helps, but should be increased with caution - can aggravate knock and overcome the high octane ratings of alcohols which make them good fumigants.
 - c. Dilution is duty cycle-dependent - less severe in vehicles which operate for long periods at stable temperatures.
 - d. Close monitoring and more frequent oil changes are probably required in any case.
3. Control of fumigant input with speed/load:
- a. Is critical to effectiveness of system and to durability of engine - below about 1/3 rated load, benefits of fumigation are very small since diesel temperatures are low at low speeds/loads and the additional cooling of fumigated alcohol may hamper ignition.
 - b. Available commercial controls are few and very simple - probably not optimum. Also, they're designed to work only with turbocharged engines.

Current turbochargers can handle some liquid if it is reasonably well atomized before entering the compressor. They cannot handle large amounts of liquid in the compressor section.

- c. Not usually possible to replace more than about 50% of diesel fuel requirement for a given load.
- 4. Subsequent engine adjustment:
 - a. Limitation of full-load fuel rate is desirable and probably necessary - total available fuel energy (diesel plus alcohol) must not exceed amount required to develop rated power - warranty implications.
 - b. Turbocharger wastegate (if one is used) may have to be adjusted - again, warranty implications.
- 5. Original Equipment Manufacturer (OEM) warranty protection:
 - a. Strictly speaking, any modifications of this sort to the engine invalidate current warranties.
 - b. Major manufacturers of farm machinery and engines for same are not enthusiastic about alcohol use in any currently available form.
 - c. Fumigation is still under evaluation by major engine manufacturers.
 - d. If fumigation is used to increase the overall fuel rate and thus to extract more than rated power from the engine, OEM warranties are definitely voided.
- 6. Power, performance, emissions:
 - a. Significant power increases may be possible but using alcohol fumigant for this purpose has engine warranty implications, since the engine may be seriously overfueled.
 - b. Smoke and particulate emissions may be decreased considerably.
 - c. Nitrogen oxides (NO_x) and carbon monoxide (CO) emissions may increase.

B. Dual-Fuel Injection with Aqueous Ethanol and Conventional Diesel Fuel

1. Materials compatibility:

- a. Excessive wear and damage to ethanol/water injector(s) may occur due to low fuel lubricity and internal corrosion (rusting) - mixing of small amounts of oil with alcohol may provide injector and pump wear protection.
- b. If "blending" is accomplished in an injection pump, diesel fuel may provide sufficient pump/injector lubrication. Corrosion problem will remain.
- c. No recognized equipment manufacturer offers dual injection equipment - used only for research purposes to date.
- d. At least one major farm tractor manufacturer specifically recommends against dual injection, citing engine knock problems.

2. Engine control and operation:

- a. In dual injection systems, engine operational range may be limited by flame quenching and/or by knock, depending on the proportion of alcohol used.
- b. Alcohol injection must be timed to begin after diesel pilot injection, otherwise alcohol may quench (extinguish) the diesel fuel flame.
- c. Petroleum conservation potential is limited by the constraints on alcohol substitution in B.2.a., above, especially in dynamic duty cycles.
- d. Idle and low load operation must be fueled with diesel fuel only.

C. Alcohol-Diesel Fuel Blends and Emulsions

1. Materials compatibility:

- a. Alcohol must be anhydrous if stable blends are to be achieved.

- b. Long-term storage stability may be degraded - alcohol(s) will extract moisture from ambient air and may thus induce phase separation.
 - c. Some increase of injection pump and/or injector wear may occur; diesel fuel will provide some lubricity to help protect these close-tolerance parts. Rusting will still be a problem, however.
 - d. Ethanol and/or higher alcohols will be required - methanol (methyl alcohol) will not blend with most diesel fuels even if anhydrous.
 - e. Emulsions, if pre-prepared using a chemical emulsifier, may be so thick and viscous as to cause great cold-weather starting difficulty.
 - f. Fuel line freezing can be a problem in cold weather regardless of whether a blend or an emulsion is used.
2. Engine control and operation:
- a. Some degree of increased combustion harshness (roughness) will probably have to be accepted.
 - b. Ignition accelerating additives can be used to smooth combustion - may prove uneconomical at required levels of mixing.
 - c. Slight advance of injection timing can also help.
 - d. Unstabilized emulsions (no chemical emulsifiers) can be made by feeding alcohol or alcohol-water to the injection pump along with diesel fuel. These can usually survive (without "breaking" or separating) long enough to be injected into the cylinders. This is not presently a commercially available option.

II. NATURALLY ASPIRATED AND TURBOCHARGED SPARK IGNITION ENGINES

A. Use as Neat (Straight) Fuel

1. Cold start:

- a. Cold startability is highly dependent on ambient temperature; 40° to 50°F is about the limit for 200° proof ethanol.

- b. Supplementary gasoline or LPG starting fuel system could be used.
 - c. No "pre-engineered" cold start systems are currently available.
2. Warm-up driveability (engine flexibility):
- a. Intake manifold and carburetor intake air heating is required - systems for both purposes are present on most late-model vehicles.
 - b. Some relatively simple modifications and/or substitutions, primarily of temperature sensing controls, can increase mixture heating somewhat.
 - c. Higher cooling system temperatures (higher cooling system thermostat rating) may help.
 - d. High-output (electronic) ignition systems may offer some help. Many OEM and aftermarket systems are available - all U.S. vehicles 1975 and newer use electronic systems.
 - e. Longer (idle-low load) engine warm-up will probably be required in any case.
3. Oil dilution (with water/ethanol):
- a. Positive crankcase ventilation (PCV) is very desirable. It is present on all vehicles 1968 and newer and should be retained.
 - b. Adequate mixture and engine heating also helps (see B.2.a.-c., above).
 - c. Dilution is duty cycle-dependent - less severe in vehicles which operate for long periods at stable temperatures, most severe in vehicles used for short trips and/or in cold weather.
 - d. Close monitoring and more frequent oil changes will probably be required in any case.
4. Diminished vehicle range and fuel economy:
- a. Pre-engineered auxiliary tanks are currently available. Auxiliary tank placement and plumbing have safety implications. The additional weight of such tanks has some negative effect on fuel economy and may reduce passenger and/or cargo space.

- b. Engine modification for significantly increased energy efficiency is expensive and relatively complex. Optimizing engine for high octane alcohol fuel(s) may limit or eliminate possibility of using gasoline in the same vehicle (Example: increased compression ratio via piston substitution and/or cylinder head machining).
 - c. At 200° proof, anhydrous ethanol is only about 2/3 as energetic a fuel as gasoline on a volume basis. At 160° proof, the per-gallon energy content is reduced to about half that of gasoline. Even with engine modification for higher efficiency, fuel economy in miles-per-gallon terms will be degraded significantly.
5. Materials compatibility:
- a. Potentially among the more difficult problem(s).
 - b. Relatively little specific, detailed information is available - in-use testing is the only unequivocal proof of performance or lack of it.
 - c. Aqueous ethanol may be more benign than neat or gasoline-blended ethanol to some materials (possiblyterne alloy). To other materials (magnesium, especially) it is more aggressive.
 - d. Close coordination with component suppliers is necessary - materials substitution is often difficult due to limited alternative materials availability.
 - e. Finding solutions to specific materials problems is largely a do-it-yourself proposition.
 - f. Electronic (or mechanical) fuel injection-equipped cars currently are not suitable for aqueous alcohol use due to materials incompatibility problems.

6. Engine rusting/corrosion:
 - a. Similar causes and (partial) solutions as in A.3.a.-d., above.
 - b. Some help may be available from certain lubricating oil brands/types/additive packages - no engine lubricants specifically formulated for such services are widely available at this time.
7. Power, performance, emissions:
 - a. With low-proof alcohol fuels, power output is usually decreased because of lower fuel energy, unless major engine modification is undertaken (see A.4.b., above). Latent heat cooling and high octane rating can help to some degree in offsetting low fuel energy content.
 - b. Emission of regulated pollutants can be reduced significantly, especially nitrogen oxides (NO_x) and hydrocarbon-type (HC) unburned fuel (UBF).
 - c. Emission of alcohols and other oxygenated UBF types will increase substantially.

B. Use as a Gasoline Blendstock

1. It is not possible due to fuel phase separation brought on by water contents greater than about 0.5 to 1.0 percent.

C. Use as an Anti-Detonant

1. Only very small amounts of petroleum can be displaced.
2. Can reduce NO_x emissions at or near wide-open-throttle (WOT), other emissions effects are small.
3. Requires a relatively complex system to deliver aqueous alcohol in accordance with engine requirements.
4. Direct improvement of power output is small - some indirect increase is available if knock suppression allows increase in spark advance.

5. Some small indirect improvement of gasoline economy is also possible if anti-detonant permits more spark advance to be used without knock.

III. SAFETY AND FUEL HANDLING CONSIDERATIONS

The alcohols are not inherently "safe" fuels per se. Care must be exercised in the handling and storage of both methanol and ethanol. The safety aspects of alcohol blends and neat alcohols are quite different.

Generally speaking, there are no adverse safety effects associated with alcohol/gasoline blends as long as the percentage alcohol is nominal (20% by volume or less). The toxicity of such blends is probably no worse than the base gasoline itself and the fuel vapors above the liquid fuel will be too rich to ignite at common ambient temperatures. Such is not the case for diesel fuel/ethanol blends (methanol is not miscible in diesel fuel). The properties of diesel fuel are such that explosive vapors could form above the diesel/ethanol fuel mixture, both in the vehicle fuel tank as well as any storage tank(s). Therefore, no spark or flame source should be allowed in the immediate vicinity of the vehicle during fueling. Additionally, if the vehicle has an in-tank electric fuel pump, the fuel level should not be allowed to drop below the pump as the pump could provide an ignition source for an explosion.

The neat alcohols have their own special set of safety-related problems. Both methanol and ethanol have extremely wide flammability limits as compared to many typical hydrocarbon fuels. This means that flammable mixtures of air and fuel vapor will be present above liquid fuel surfaces under most ambient conditions. This, coupled with the alcohols' relatively low flash points, demands extreme care in storage and handling. However, it has been determined that the addition of about 20-30 volume percent gasoline to neat alcohol will narrow the flammability limits, making the vapor too rich to ignite at most ambient conditions.

Neat methanol presents some safety problems which separate it from ethanol. Methanol is an extremely toxic substance.

Ingestion of as little as 1-2 ounces can result in death. Blindness can be incurred from ingestion of even smaller quantities. Methanol can be absorbed through the skin with the same results. Additionally, methanol is a tasteless, low-odor substance which burns with an invisible flame. Fortunately, the addition of gasoline will reportedly solve the problems of low odor and low flame visibility. Roughly the same percentages of gasoline (20-30) are required as are used to narrow the flammability limits of neat alcohol fuels.

There may be certain safety-related legalities associated with the use of neat alcohols in both mobile and stationary applications. It would be advisable to ascertain that one's automobile insurance will cover the use of neat alcohols.

The use of neat alcohols for home furnaces may be in violation of local housing codes and/or may require the installation of a special storage tank and ancillary equipment. In general, check all codes, regulations, insurance requirements, etc., prior to storing and/or utilizing neat alcohols.

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