SUBSTITUTION OF ALCOHOL
FOR DIESEL FUEL
IN COMPRESSION IGNITION ENGINES

Final Report

When applying for our grant funds, our basic objective was to get a compression ignition engine to run properly utilizing at least 50% wet alcohol of a proof that could be easily produced on a farm. In order to do this, we proposed a mixture of diesel fuel, wet alcohol, and used engine oil that had been properly filtered and cleaned, plus whatever additives that would be required to hold this mixture in a micro-emulsion. Once we were able to complete our first objective, we would start on our second main objective of determining what effects these fuel mixtures would have on the operation and wear of the diesel.

In our work, we have run into one major obstacle of not being able to find an emulsifier that will emulsify the combination of diesel, wet alcohol, and used engine oil. With the used engine oil being the one ingredient giving us the most problems, we tried substitutes. We have been able to utilize a near 50% alcohol fuel by substituting a vegetable oil for the used engine oil and combining ethyl and butyl alcohol at different proportions according to the proof of the wet alcohol.

PROCEDURES

Step 1: We purchased a 1370 Case Farm tractor for our test unit. We selected the Case because the Robert Bosch In Line Pump is used on this unit and we felt this gave us the most flexibility in adjusting fuel deliveries. The engine was completely dismantled, all parts examined, and a micrometer used for future reference concerning engine wear. The engine was rebuilt to original condition. The engine was then run on a dynamometer for a break-in period on diesel fuel. After the break-in period, the engine was run on dynamometer and all engine data was recorded for comparison with the alcohol fuel mixtures.
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The instrumentation placed on the tractor is: oil pressure, turbo boost pressure, water temperature, oil temperature, intake manifold temperature, exhaust manifold temperature, and horsepower. Prior to all test, the tractor was allowed to reach operating temperatures before data was recorded by applying varying loads with the dynamometer. The following results were recorded on #2 diesel fuel:

1050 PTO RPMS or 2100 Engine RPMS

Oil Pressure--------------40-45 p.s.i.
Turbocharger Boost Pressure---------12.5 p.s.i.
Water Temperature------------------190-1950F
Oil Temperature---------------------210-2150F
Intake Manifold Temperature--------3100F
Exhaust Manifold Temperature-------1030-10500F
Horsepower------------------------135 PTO Horsepower

The engine fuel system was then overrated by approximately 25% because of our anticipated losses of horsepower when using the alcohol fuel mixtures.

The following results were then obtained using #2 diesel fuel with the overrated fuel system:

1050 PTO RPMS or 2100 Engine RPMS

Oil Pressure--------------40-45 p.s.i.
Turbocharger Boost Pressure---------14.5-15 p.s.i.
Water Temperature------------------190-1950F
Oil Temperature---------------------205-2100F
Intake Manifold Temperature--------3000F
Exhaust Manifold Temperature-------1040-10600F
PTO Horsepower---------------------160 PTO Horsepower

Step 2:

Since no one on the Alcomotive staff had a background in chemistry, Bill McFadden of Prairie Power, Inc. in Springfield, Illinois was hired under contract to do the experimentation with the emulsifiers to be used in our fuel combinations. Bill is a graduate chemical engineer and president of Prairie Power, Inc. with fifteen years experience as an engineer. This experience includes work with A. E. Staley in Decatur, Phelps-Dodge in Ft. Wayne, Indiana, and the last five years as president of Prairie Paint and Adhesive Company in Springfield, Illinois.
Bill's background in paints and in wet and dry milling processes gave him a strong background for such work. Our first step was to evaluate the alcohol and the diesel fuel to be used in the fuel mixtures. The following was determined:

**Alcohol Sample #1** from Farm Energy Co-op, Indianola, Illinois
- Hydrometer Readings (3 taken) -- 190° proof corrected to 60°F
- Denaturant -- 5% methy isobutyl ketone (MIBK)
- Moisture (Karl Fisher Apparatus) -- 8.0%
- Specific Gravity -- 0.816
- pH -- 5.8

**Diesel Fuel Sample #1**
- Moisture -- 0.01%
- Weight / Gal. -- 6.94 lbs.
- Weight of Oil / Gal. -- 7.3 lbs.

**Alcohol Sample #2** from Evan Leefer's Farm, Carlinville, Illinois
- proof -- 184° proof at 60°F

After some preliminary blending experiments it became obvious that a standard blend is necessary to learn which variables cause the phase separation. Using Mr. Leefer's of Carlinville wet alcohol (184° proof @ 60°F) and the five gallons of diesel fuel from Roger Webb, various blends were made with butanol, hydrelate, several other additives and linseed oil. The constant proportions were 47 parts diesel, 24 parts wet alcohol, and 5 parts boiled linseed oil.

<table>
<thead>
<tr>
<th>ADDITIVE</th>
<th>PARTS TO GET CLEAR SOLUTION - ROOM TEMP.</th>
<th>PARTS TO GET CLEAR SOLUTION - 0°F OVERNIGHT</th>
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<tr>
<td>Butanol</td>
<td>34</td>
<td>44</td>
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<tr>
<td>Additive I</td>
<td>32</td>
<td>40</td>
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<tr>
<td>Additive II</td>
<td>45</td>
<td>62</td>
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<tr>
<td>Hydrelate</td>
<td>24</td>
<td>30</td>
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</tbody>
</table>
It is concluded that it is technically feasible to get clear fuel solutions that are stable; however, the economics are poor.

These same solutions were made using VALVOLINE SAE 30 wt. oil in place of linseed oil. All solutions were cloudy and the oil settles to the bottom.

Step 3:

At room temperatures it was found that mixtures containing 47.5% diesel fuel, 23.75% 189°proof ethyl alcohol, 23.75% Butanol and 5% of the following vegetable oils would remain blended for reasonable amounts of time. The vegetable oils used to make samples were corn, sunflower, and linseed. Five gallon samples using the different oils were blended and were initially run through the tractor to obtain some preliminary results. Again, before each test the tractor was warmed up on diesel fuel to operating temperatures before the trial sample was run. The results were as follows:

5% Corn Oil

1050 PTO RPMS or 2100 Engine RPMs
Oil Pressure-------------------40-45 p.s.i.
Turbo Boost Pressure----------12-12.5 p.s.i.
Water Temperature-------------190-195°F
Oil Temperature---------------210-215°F
Intake Manifold Temperature---290-300°F
Exhaust Manifold Temperature---910-920°F
Horsepower--------------------120-122 at PTO

5% Sunflower Oil

1050 PTO RPMS or 2100 Engine RPMs
Oil Pressure-------------------40-45 p.s.i.
Turbo Boost Pressure----------11.5 p.s.i.
Water Temperature-------------190-195°F
Oil Temperature---------------205-210°F
Intake Manifold Temperature---290-300°F
Exhaust Manifold Temperature---930-940°F
Horsepower--------------------120-121 at PTO
For comparison, samples were run with 200 proof alcohol and diesel fuel blends as well as dieselfuel, wet alcohol, and butanol blends. The results of the tests are as follows:

**66% Diesel Fuel 17% 189°proof alcohol and 17% Butanol**

1050 PTO RPMS or 2100 Engine RPMS

- Oil Pressure: 40-45 p.s.i.
- Turbocharger Boost Pressure: 11 p.s.i.
- Water Temperature: 185°F
- Oil Temperature: 200°F
- Intake Manifold Temperature: 185°F
- Exhaust Manifold Temperature: 1,110°F
- Horsepower: 135

**60% Diesel Fuel 20% 189°proof alcohol and 20% Butanol**

1050 PTO RPMS or 2100 Engine RPMS

- Oil Pressure: 40-45 p.s.i.
- Turbocharger Boost Pressure: 14 p.s.i.
- Water Temperature: 190-195°F
- Oil Temperature: 205-210°F
- Intake Manifold Temperature: 300°F
- Exhaust Manifold Temperature: 950°F
- Horsepower: 128-130

**65% Diesel Fuel 35% 200°proof anhydrous alcohol**

1050 PTO RPMS or 2100 Engine RPMS

- Oil Pressure: 40-45 p.s.i.
- Turbocharger Boost Pressure: 12-12.5 p.s.i.
- Water Temperature: 190-195°F
- Oil Temperature: 205-210°F
- Intake Manifold Temperature: 260-280°F
- Exhaust Manifold Temperature: 930-940°F
- Horsepower: 128-132

**5% Linseed Oil**

1050 PTO RPMS or 2100 Engine RPMS

- Oil Pressure: 40-45 p.s.i.
- Turbocharger Boost Pressure: 11 p.s.i.
- Water Temperature: 185°F
- Oil Temperature: 200°F
- Intake Manifold Temperature: 185°F
- Exhaust Manifold Temperature: 1,110°F
- Horsepower: 135 at PTO
60% Diesel Fuel 40% 200°proof alcohol

1050 PTO RPMs or 2100 Engine RPMs

- Oil Pressure: 40-45 p.s.i.
- Turbocharger Boost Pressure: 13 p.s.i.
- Water Temperature: 190°F
- Oil Temperature: 205°F
- Intake Manifold Temperature: 290°F
- Exhaust Manifold Temperature: 950°F
- Horsepower: 135 at PTO

It is important to note that at this level of anhydrous alcohol, fuel injection problems began to develop and in a fifteen minute time period, the tractor horsepower had dropped to 130 and there were signs of engine miss firing. The engine was placed back on 100% diesel fuel to be sure engine would return to proper horsepower rating.

50% Diesel Fuel 50% Anhydrous Alcohol

Engine only runs 13 minutes on this mixture before seizing injection pump. The highest horsepower was recorded at 119-120 but declined steadily. With the wild fluctuations, other data was not recorded in this test.

The Case tractor was then prepared for field operations.

Step 4:

It was decided that for the field testing of the tractor, the combination of 47.5% diesel, 23.75% 189°proof, 23.75% butyl alcohol, and 5% linseed oil would begin the test. We attempted to utilize each fuel blend for at least a 25 hour test. During the field operations, data will be recorded. (See Attachment #1) and records of fuel consumption will be recorded.

For field operations, 400 # of ballast were added to the front end of the tractor. The rear wheels were dualled when needed. The duals added 1200 lbs. of ballast. The tractor had a total ballast of 15,000 lbs. Most field operations were done in a speed range of 5-8 m.p.h.
The tractor was operated in field type operations for a total of 186 tachometer hours. The tractor was used for normal field usage during the spring and fall seasons of 1981. Included in the operations were plowing with 6 bottom 16" plow, disking with a 24' IHC Disk, harrowing with a 24' Harrogator, chiesel-plowing with a 12' Case Soilsaver, as well as applying anhydrous ammonia with a 21' applicator. The tractor was operated on seven different fuel combinations containing ethyl alcohol. Of the seven combinations, four were used for at least 20 tachometer hours. The test fuel combinations and their hours of operation are as follows:

1. 47.50% Diesel Fuel  
   23.75% 187° Ethanol  
   23.75% Butanol  
   5.00 Linseed Oil  
   89.8 Hours  
   6.38 gph (gallons per hour)fuel usage

2. 52% Diesel Fuel  
   26% Ethanol (Anhydrous)  
   17% Butanol  
   5% Corn Oil  
   1.5 Hours

3. 47% Diesel Fuel  
   23% Ethanol (187°)  
   23% Test Emulsifier  
   7% Corn Oil  
   4.2 Hours

4. 47% Diesel Fuel  
   28% Anhydrous Alcohol  
   19% Test Emulsifier  
   6% Corn Oil  
   7.4 Hours

5. 47% Diesel Fuel  
   28% Anhydrous Alcohol  
   19% Test Emulsion  
   6% Peanut Oil  
   27 Hours  
   7.41 gph

6. 47% Diesel Fuel  
   28% Anhydrous Alcohol  
   19% (50/50 combination of butanol and test emulsifier)  
   6% Linseed oil  
   21.2 Hours  
   7.07 gph
7. 47% Diesel Fuel 22 hours 6.82 gph
28% 187 proof ethanol
19% Test emulsifier
6% Corn oil

When blending the fuels, we had the following major obstacles to keep in mind:
1. Providing lubrication for tolerance in injection fuel system.
2. Keeping alcohol levels as high as feasible.
3. Providing an emulsifier to keep all combinations in suspension.

We initially had good results with the first combination we used in the tractor. We used this combination for almost 90 hours of tractor operation. We did have a slight governor problem with injection governor sometimes holding open. We decided this was caused by a lack of lubricating value of mixture and we then raised the % of oils to 6 or 7%. The problem did not resurface on any of the later mixtures. There was also a problem of gumming with the boiled linseed oil. We did not have this gumming problem with the corn oil or peanut oil. We believe this has to do with the refinement of the oil mixtures.

The tractor ran normally during all field operations. All the instrumentation readings were recorded hourly during field operations. However all readings were normal and varied little with the different fuel combinations. The ranges during operation are as follows:

Water temperature---------------------170-200°F
Oil pressure--------------------------40-47 p.s.i.
Oil temperature----------------------200-230°F
Intake Temperature-------------------150-230°F
Pyrometer-----------------------------500-700°F
Turbo Pressure-----------------------7-10 p.s.i.
Tachometer--------------------------1900-2100
It is important to note that at all times the exhaust manifold temperature was significantly reduced while operating on the alcohol fuel mixtures in the field. This was also confirmed by our earlier dynamometer tests. With diesel fuel, the pyrometer readings were 1000°F ± under load, while the range for the alcohol mixes was from 500-700°F. This is one positive aspect we would see with the alcohol fuel blends.

All of the hybrid fuel blends had two major problems. One was poor engine starting capabilities, and the second was the high levels of emulsifiers required to keep the fuel blends in emulsion. I would like to discuss each of these problems in some detail.

In warm weather conditions (80°F days--50°F nights) the tractor could be started directly on the hybrid fuel mixtures, but the ether injection system was required to give the engine initial firing capabilities with a cold engine. During the remainder of the work day, the engine would start normally without the ether assist. The engine would take a minute or two to warm up before running normally. In cooler weather (70°F days--40°F nights) the engine was more difficult to start on the hybrid fuel mixture. In many instances, the tractor would need to be kept running for one to two minutes on ether before it would take over and run on the fuel mixture; then several minutes of idling was required before the engine would run normally. The tractor would then usually start normally the rest of the day, but would sometimes rough idle temporarily.

In cold weather (below 50°F) we started the tractor on diesel fuel and then switched to fuel mixtures. The tractor was very difficult to get running on fuel mixtures in cooler weather. After warmup, the tractor would run normally on fuel mixture as long as the mixture remained in emulsion. Cetane improvers would need to be investigated for continued use of hybrid fuels as concurred by paper 80-1523 American Soc. of Agriculture Engineers 1980.
The amount of emulsifier required for the hybrid fuel mixtures is controlled by:

a. proof of alcohol used in hybrid mixture
b. temperature levels at which you want to maintain emulsion
c. length of time you want to maintain in emulsion

In the seven fuel mixtures we field operated, the tractor on our percent range of emulsifiers ranged from 17-24% of the total blend, while the proof of alcohol ranged from 187° proof to anhydrous alcohol.

We purchased some 180° proof alcohol for blending, however, the lower proof alcohol was requiring over 30% of the total mixture to be emulsified in order for the fuel mixture to remain stable at room temperature. We felt that these percentages of emulsifiers were prohibitive and continued our testing with alcohols of 185° proof or higher.

Engine wear was evaluated in two ways. The first was through engine oil analysis in which oil samples were taken every 25 hours of engine operation and submitted to D+I Analysis in Springfield, Illinois. The samples were then evaluated for copper, silicon, iron, chrome, nickel, lead, silver, aluminum, sodium, Base #; S.A.E., fuel dilution, water and insolubles. (See attachments) During operation on the fuel blends, all wear metals remained within allowable levels. After engine work, some metal levels were above limits, however, this is expected when engine work takes place.

Secondly, the engine was dismantled for the second time at 2871 tachometer hours. At this time we had over 150 hours utilizing the alcohol fuel mixes. Our mechanic could find nothing to indicate that engine wear was excessive during the period of using the alcohol fuel mixtures. The engine was
then put back in operation and run an additional 30 hours on the hybrid fuel blends.

In summary, our findings are as follows:

1. 185-200° proof alcohol and diesel fuel will not blend and remain stable without the presence of an emulsifier.

2. The amount of emulsifier required correlates directly with the proof of the alcohol.

3. There are definite starting problems with hybrid fuel mixtures, probably due to the poor cetane rating of the fuel mixes.

4. Some type of an oil base needs to be added to the fuel mixture when alcohol levels get to be over 20%. Of the fuel mixtures, peanut and corn oil worked well for us at about 6 or 7% of the total blend. Linseed oil ran well in the engine, but left a gummy deposit on external engine parts.

5. Engine fuel systems will need to be overrated due to the reduced BTUs of hybrid fuels. For example, on diesel fuel, tractor horsepower was 160 at the PTO. When it was placed on first hybrid fuel, PTO horsepower dropped to 123.

6. Exhaust manifold temperature was significantly reduced with the hybrid fuel blends.

7. There does not seem to be any additional engine wear utilizing the fuel blends.

8. There was a visible reduction in exhaust smoke on fuel mixes. We did not have instrumentation to measure these exact levels of smoke reduction.

9. Once the engine was warm, it performed very normally in all respects.

10. We were never able to utilize the used engine oil, as it would separate and not stay blended in the mixture. We did not have anyone with enough understanding of emulsifiers to overcome this problem. That's not to say the idea isn't practical and that a good chemist couldn't find the proper emulsifier.

11. The economics of these mixtures are very poor at this time.
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## Automotive Wear Rate Specs

### Gasoline Engines - Typical Values

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<tr>
<th>Element</th>
<th>Acceptable</th>
<th>Reportable</th>
<th>Unacceptable</th>
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<td>Iron</td>
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<td>Silicon</td>
<td>Below 20 ppm</td>
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**NOTE:** Values may vary widely from those listed above. Operating conditions have a large effect on wear metal levels. In addition, the materials used in manufacturing gasoline engines vary from one model to another. Any analysis should be based on the trend of readings after several samples.
<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>DATE</th>
<th>EQUIP. HOURS/ MILES</th>
<th>OIL HOURS/ MILES</th>
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**SAMPLE NO. (2170):** This engine will soon be put on diesel alcohol oil and emulsified water metal drill high from engine block and will be for a winter season. Please suggest a shell to use to illinois from lubricant.