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EVALUATION OF SOYBEAN OIL-AQUEOUS ETHANOL MICROEMULSIONS FOR DIESEL ENGINES

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ABSTRACT

Hybrid fuels, formed by microemulsifying aqueous ethanol in soybean oil, were evaluated by burning them in a diesel engine. No. 2 diesel fuel was also burned to provide baseline data. The hybrid fuels performed nearly as well as No. 2 diesel despite having lower cetane numbers and less energy content. At present, the hybrid fuels are more expensive than No. 2 diesel fuel and their effect on engine durability is unknown.

INTRODUCTION

Dr. Rudolph Diesel used peanut oil to fuel one of his engines at the Paris exposition of 1900 (Nitscke and Wilson, 1965). Intermittently since then, there have been other studies on the use of vegetable oils as fuel for diesel engines. Recently, the foreseeable depletion of world petroleum reserves and the instability of conventional petroleum sources has generated renewed interest in such studies.

Neat vegetable oils are too viscous for prolonged use in direct-injected diesel engines, and several techniques are being used to reduce fuel viscosity. Viscosity can be reduced by blending the vegetable oil with other, less viscous liquid fuels and the resulting blends have been termed hybrid fuels. The most popular hybrid diesel fuels have resulted from the blending of vegetable oils with conventional diesel fuels. Nonpetroleum hybrid fuels would be preferable in the longer term to completely eliminate dependence on petroleum. Several organic solvents are available for blending into nonpetroleum, hybrid fuels for diesel engines.

Ethanol is an organic solvent that can be produced in rural communities from agricultural feedstocks. However, neither anhydrous nor aqueous ethanol are

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directly miscible with most vegetable oils. Immiscible liquids can be joined into macroemulsions (i.e., ordinary emulsions), but continued agitation is required to sustain such emulsions. Use of microemulsions eliminates the need for agitation.

Microemulsions are transparent, thermodynamically stable colloidal dispersions in which the diameter of the dispersed-phase particles is less than one-fourth the wavelength of visible light (Boruff, et al., 1982). The microemulsions form spontaneously when suitable surfactants are used to sufficiently reduce the interfacial tension between the dispersed and continuous phases. Hybrid fuels of special interest are water-in-oil type microemulsions in which the vegetable oil is the continuous phase and aqueous ethanol forms the dispersed phase.

In the research reported herein, organically derived surfactants were used to microemulsify aqueous ethanol (190 proof) with soybean oil. Soybean oil was chosen because it is least expensive of the domestically grown vegetable oils and is available in the largest quantities (Goering and Daugherty, 1981). Two series of hybrid fuels that were investigated were ionic and nonionic microemulsions of aqueous ethanol in soybean oil. The objective of the study was to evaluate the hybrid fuels by burning them in a diesel engine.

FUEL PROPERTIES

The compositions (by volume) of the hybrid fuels are given in Table 1. SAE Standard J313C (SAE, 1979) establishes limits for certain key properties of No. 2 diesel fuel. Table 2 compares certain of those limits with measured properties of the nonionic hybrid fuel. Properties were measured using standard ASTM procedures (ASTM, 1981). The hybrid fuels were not tested for water and sediment, ash, and total and active sulphur because earlier research had shown that the components of the hybrids were very low in these contaminants (Goering, et al., 1981a; Goering, et al., 1981b). Distillation temperatures were not measured because earlier research had shown that vegetable oil cracks during distillation (Goering, et al., 1981a). While they are not shown in Table 2, the fuel properties of the ionic microemulsions would differ little from those of the nonionic microemulsion, except that the viscosity of the former was 8.77 mm^2/s.

Table 1. Composition of the Hybrid Fuels

Fuel Component	Chemical Formula	Fuel Ionic Hybrid	 Nonionic Hybrid
Soybean oil	--	52.3	53.3
190-proof ethanol	C_2H_6O	17.4	13.3
1-butanol	$C_4H_{10}O$	20.5	33.4
Linoleic acid	$C_{18}H_{32}O_2$	6.54	0
Triethyl amine	$C_6H_{15}N$	3.27	0

Calculated properties of the hybrid fuels and of diesel fuel are shown in Table 3. The higher heating values (HHV) of the hybrid fuels were calculated from component HHV's that were measured by the ASTM standard bomb calorimeter method (ASTM, 1981). The HHV's of the hybrid fuels were approximately 81% of that of No. 2 diesel fuel. The stoichiometric air-fuel ratios of the hybrids were approximately 79% of that of No. 2 diesel. Fuel properties differed

Table 2. Comparison of Fuel Properties

Property	ASTM Method	Fuel Nonionic Hybrid	 Limits for No. 2 diesel
Flash point, °C	D93	27.8	51.7 min
Cloud point, °C	D2500	a	b
Pour point, °C	D97	-65	c
Water & Sediment, %	D1796	-	0.05 max
Carbon residue, %	D524	0.18	0.35 max
Ash, %	D482	-	0.01 max
Dist. temp. at 90% point, °C	D86	-	282-338
Viscosity at 37.8°C, mm^2/s	D445	6.77	1.9-4.1
Total sulphur, %	D129	-	0.05 max
Active sulphur, %	D130	-	d
Cetane No.	D613	25.1	40 min

[a] Cloud points were not attempted because fuel separated into 2 layers at 0°C.

[b] Specified at 6°C above the tenth percentile minimum ambient temperature.

[c] Not specified by SAE but usually 4 to 6°C below cloud point.

[d] Test interpreted by comparison of immersed copper strip with standard immersed strips.

Table 3. Calculated Properties of the Fuels

Property	Fuel Ionic Hybrid	 Nonionic Hybrid	 No. 2 diesel
Higher heating value, kJ/kg	36687	37045	45343[a]
Stoichiometric A/F ratio	11.60	11.57	14.55

[a] Measured.

little between the hybrids except that the ionic hybrid was more viscous.

The cetane rating of the hybrids was well below the SAE minimum for No. 2 diesel fuel (Table 2) and so use of a cetane improver was investigated. Figure 1 shows the effect of primary akyl nitrate (PAN) on the cetane number of the nonionic hybrid fuel. A 10% concentration is a massive amount of PAN and this was the amount required to bring the cetane rating of the nonionic microemulsion to the minimum of 40 for No. 2 diesel fuel.

EQUIPMENT

A John Deere[*] Model 152 power unit was used for testing the fuels. John Deere Model 830 tractors use the same engine. The three-cylinder, naturally aspirated direct-injection diesel engine displaced 2.491 liters and was rated at 26.3 kW at a speed of 2400 rev/min. The engine used a Roosa Master distributor type injection pump with normal injection advanced 26° before head

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[*] The mention of firm names or trade products does not imply that they are endorsed or recommended by the University of Illinois or the U.S. Department of Agriculture over other firms or similar products not mentioned.

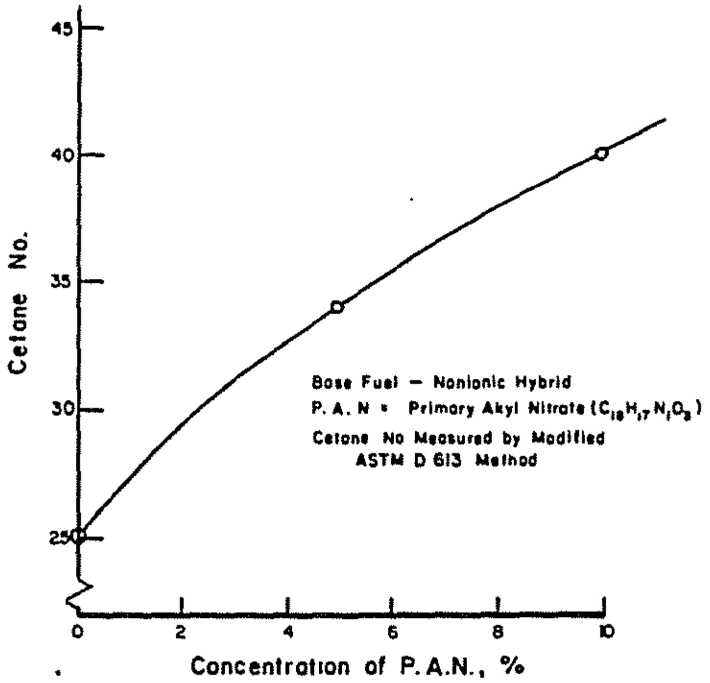

Figure 1. Cetane Enhancement of a Hybrid Fuel

dead center. The engine was connected through an overcentering clutch to a Midwest Dynamic Type-768 eddy current dynamometer. Fuel consumption and engine speed were measured through use of an automatic weighing system and a standard chronotachometer that measured elapsed time and engine revolutions while 100 grams of fuel were being burned. Chromel-alumel thermocouples and an Omega model 199 digital indicator were used to monitor exhaust and coolant temperatures. A counter flow heat exchanger with automatic control of secondary water was used to regulate the temperature of the engine coolant. Air was supplied to the engine through an orifice meter connected to a double surge tank. A calibrated, inclined manometer permitted measurement of the pressure drop across the orifice. The double surge tank included a boost fan to maintain atmospheric pressure at the inlet of the engine.

PROCEDURE

The engine was started and run on No. 2 diesel fuel until the coolant reached the controlled temperature of 89±3°C. A baseline test was then run on No. 2 diesel fuel. Loading began at 2527 rev/min high idle speed and increased until governor's maximum speed was reached. At each load, the load, speed, fuel and air consumption and exhaust and coolant temperatures were measured.

After completion of the baseline run, the engine was switched to the nonionic hybrid fuel, the fuel return line was diverted to a waste container, and the engine was run until the diesel fuel was flushed from the system. The same test procedure used in the baseline tests was then repeated for the nonionic hybrid fuel.

The ionic hybrid fuel was then tested using a procedure similar to that for the nonionic hybrid. Finally, a second baseline test was run on No. 2 diesel fuel.

RESULTS

Figure 2 and Table 4 show the key results of the engine tests. Although the hybrids contained 19% less energy per kilogram than No. 2 diesel fuel (Table 3), the nonionic microemulsions was able to produce almost the same peak power as diesel fuel (Table 4). The ionic microemulsion produced 5% less

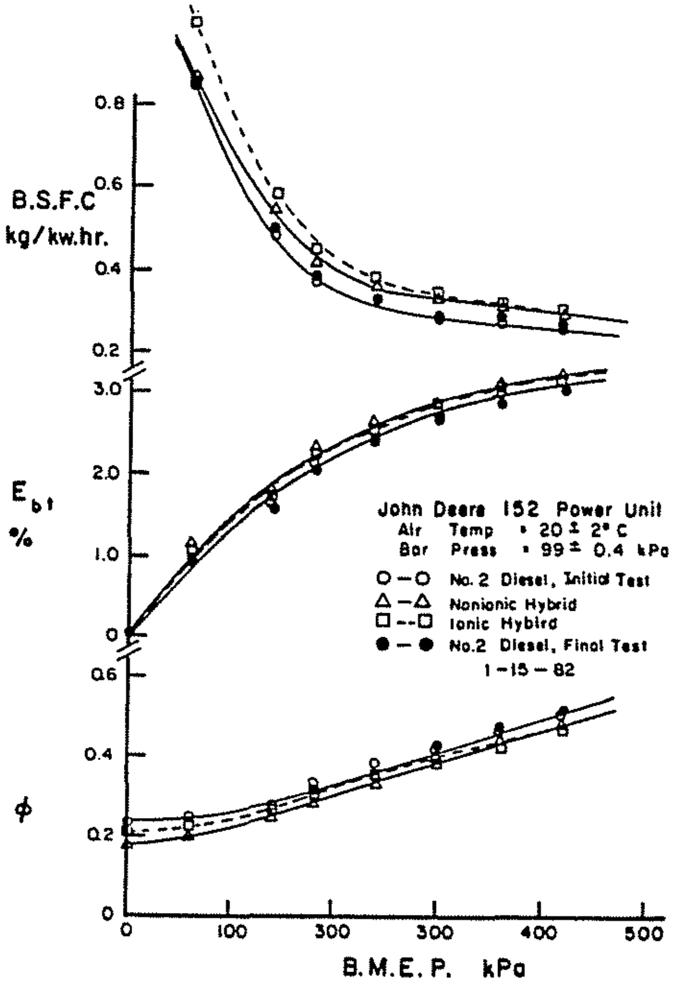

Figure 2. Performance of a Diesel Engine or Diesel and Hybrid Fuels.

Table 4. Engine Performance at Maximum Power

Test fuel	Max Power kW	Fuel Supplied mg/injection	Energy Supplied kJ/injection	Brake Thermal Efficiency %
No. 2 diesel	24.1	86.1	3.91	30.5
Ionic hybrid	22.9	101.2	3.71	32.2
Nonionic hybrid	23.7	99.9	3.70	32.3
No. 2 diesel	23.9	86.9	3.94	30.3

power than No. 2 diesel. The higher viscosity of the hybrids increased the size of the fuel injections (Table 4), but not enough to achieve equal energy per injection. The approximately 6% less energy per injection of the hybrids was offset by a corresponding gain in brake thermal efficiency, and so enabled the engine to produce more power than was expected.

The engine speeds (and thus the mechanical efficiencies) were essentially the same for all of the fuels tested. As indicated by the equivalence ratio (Ø, or the actual fuel-air ratio divided by the stoichiometric fuel-air ratio) in Figure 2, the hybrid fuels burned leaner than diesel fuel because of the oxygen contained in the hybrids. The leaner burn gave better thermal efficiency for the hybrids. Although the increased efficiency and increased fueling rate were able to maintain high power output of the engine on the hybrid fuels, the brake specific fuel consumption (BSFC) was higher with the hybrids as shown in Figure 2. All of the data in Figure 2 are plotted against brake mean effective pressure (BMEP), or specific torque. For the 2.491 L test engine, the torque in Newton meters would be 0.198 times the BMEP.

DISCUSSION

The low cetane numbers of the hybrid fuels had no adverse effect on their short-term performances in the engine. The engine ran well on the hybrid fuels after warmup, and the audible diesel knock was the same as for No. 2 diesel fuel. Cold starting with the engine at room temperature was easily achieved on the hybrid fuels by using an ether assist. The cetane number of the hybrids does not seem indicative of their performance. A study is needed to evaluate the energy release patterns of the hybrid fuels during combustion, and such a study is now underway at the University of Illinois.

The safety aspects of hybrid fuels must be considered. The most volatile component of the hybrid fuels was ethanol, with a flash point of 14.4°C. The flash point of the nonionic hybrid fuel was 27.8°C and, based on similarity of composition, the flashpoint of the ionic hybrid would be close to 27.8°C. Thus, the hybrid fuels are less volatile than ethanol and could be handled with procedures considered to be safe for handling ethanol.

The effect of the hybrid fuels on engine durability has not yet been determined. The short-term performance tests were accomplished in 3.5 hours. There was no degradation in engine performance during that time because, as shown in Figure 2, the final run on No. 2 diesel fuel substantially reproduced the initial run. Exhaust temperatures averaged from 15 to 37°C lower with the hybrid fuels as the load increased from idle to governor's maximum. The cooler burning would be helpful to exhaust valves and other temperature-stressed parts. However, many more hours of testing will be required to evaluate the effect of the hybrid fuels on engine durability.

The cost per liter of fuel is estimated to be $0.54 for the ionic hybrid, $0.48 for the nonionic hybrid and $0.24 for No. 2 diesel fuel at the wholesale level. The price of diesel fuel is currently depressed because of the current economic recession and the glut of petroleum on the market. Until petroleum prices rise and the price gap narrows, the hybrid fuels are not competitive with petroleum. However, theprice of petroleum could rise quickly if oil imports were interrupted, and the hybrid fuels could then compete as emergency fuels. In the longer term, world reserves of petroleum will be depleted and all fuels will have to be renewable.

SUMMARY AND CONCLUSIONS

Hybrid fuels were formed by creating microemlusions of aqueous ethanol in soybean oil. A nonionic microemulsion was formed by using 1·butanol as a surfactant, and an ionic microemulsion was formed by using a mixed surfactant. The objective of this study was to evaluate the hybrid fuels by burning them in a diesel engine and to compare them to the No. 2 diesel fuel that was burned in baseline tests. The following conclusions were drawn from the study:

1. The nonionic microemulsion produced nearly as much engine power as No. 2 diesel fuel despite having a 19% lower heating value.
2. Increased viscosity of the hybrid fuels gave a 16% increase in the mass of each fuel injection at maximum power, but the injections contained 6% less energy than those of No. 2 diesel fuel.
3. Oxygen in the hybrid fuels produced leaner combustion and yielded a 6% gain in thermal efficiency over No. 2 diesel fuel at full power.
4. Brake specific fuel consumption was 16% higher with the hybrids than with No. 2 diesel fuel at full power.
5. The nonionic fuel gave slightly higher thermal efficiency, higher engine power and lower specific fuel consumption than the ionic hybrid and thus was slightly more effective as a fuel.
6. Diesel knock was no worse for the hybrid fuels than for No. 2 diesel fuel and thus the low cetane numbers of the hybrid fuels was not reflected in engine performance.
7. The hybrid fuels were less volatile than ethanol and thus could be handled safely with procedures considered safe for ethanol.
8. The effect of the hybrid fuels on engine durability is unknown and should be determined before the fuels are commended for general use.
9. The hybrid fuels are currently too expensive to compete with No. 2 diesel fuel but could serve as an emergency fuel if petroleum supplies were interrupted.

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