ONE-THOUSAND-HOUR ENGINE DURABILITY TEST WITH HYSEE AND USING A 5X-EMA TEST CYCLE

C. L. Peterson, J. C. Thompson, J. S. Taberski

ABSTRACT. *A modified 1000-h EMA-based test was run on three Yanmar 3TN75E-S 15 kW (20 hp) diesel engines fueled with three different blends of hydrogenated soy ethyl ester (HySEE). Fuels used in the test were 100%, 50%, and 25% blends of HySEE with type 2 diesel fuel (D2). Eight-thousand one-hundred and five liters (2141 gal) of HySEE were produced for the test using the process developed at the Department of Biological and Agricultural Engineering at the University of Idaho. The blends of HySEE performed adequately compared to diesel fuel. However, cold weather operation was a continual challenge. At each of the normal oil change intervals, oil analysis results for wear metals for the 100% HySEE engine were equal to or better than either the 25% HySEE or the 50% HySEE fueled engine. Engine injector pressure and compression was essentially unchanged for all engines over the course of the 1000 h. The engine fueled with 100% HySEE was cleaner and brighter internally than either the 25% HySEE or the 50% HySEE fueled engine. The 25% HySEE fueled engine was overfueled in the torque range according to a post injector pump test.*
Keywords. *Engine fuels, Renewable fuels, Biodiesel, Hydrogenated soy ethyl ester, Durability tests, EMA test cycle.*

The Engine Manufacturer's Association (EMA) in 1982 adopted a 200-h preliminary durability screening test to assess the potential impact of alternative fuels on diesel engine durability (EMA, 1982). The test is intended for research and development purposes and is designed to initiate durability problems in a short amount of time. Successful completion of the test is no assurance that a fuel will be acceptable, however the test does help to eliminate some candidate fuels.

Due to increasing environmental awareness, biodiesel is gaining recognition in the United States as a renewable fuel and it may be used as an alternative to diesel fuel with no engine modifications. Biodiesel can be made from ethanol and vegetable oil which are both agriculturally derived products. Biodiesel made from such renewable resources is safer due to increased flash point, biodegradable, containing little or no sulfur, and tending to reduce visible smoke from the exhaust. Currently, biodiesel is very expensive to make from new feedstocks. One way to reduce the cost of biodiesel is to use less expensive feedstocks such as used fryer oil from the food processing industry.

Vegetable oil as an alternative fuel (Biodiesel) has been under study at Idaho since 1979. Researchers at Idaho have pioneered the use of vegetable oil, particularly rapeseed oil (*Brassica napus*), as a diesel fuel substitute. Although short term tests using neat vegetable oil have shown promising results, longer tests led to injector coking, more engine deposits, ring sticking, and thickening of the engine lubricant. This experience has led to the use of modified vegetable oil as a fuel. Although there are many processes for modifying vegetable oil for fuel use, the transesterification process has been found to be the most viable for Idaho researchers.

Idaho produces approximately 15 650 000 kg (34,502,000 lb) of potatoes from over 152 000 ha (375,600 acres) of land. Nearly 60% of these potatoes are processed, mostly into french fries. French fry processing plants use hydrogenated oils because of their stability at higher temperatures and ease of handling the frozen product. Typically, the hydrogenated oils used in such processes are derived from soybeans because of their relative abundance in the United States. It is estimated that there are several million kilograms of waste vegetable oil available from these operations each year. Additional waste frying oil is available from smaller processors, off-grade seeds, and restaurant deep fryers.

Simplot's Caldwell, Idaho, facility offers a unique combination of resources in a single location. In addition to processing potatoes into french fries, Simplot also produces fuel grade ethanol from its potato wastes. From a single facility comes the two main ingredients to make biodiesel—vegetable oil and alcohol.

This project required the production of 7571 L (2000 gal) of hydrogenated soy ethyl ester (HySEE) using the process developed at the Department of Biological and Agricultural Engineering at the University of Idaho. The fuel was used to run 1000 h engine tests in the Long Term Engine Test Facility. The cycle used was the 200-h alternative fuel durability test cycle proposed by EMA repeated five times. Fuels used in these tests were 100%, 50% and 25% blends of HySEE with no. 2 diesel fuel.

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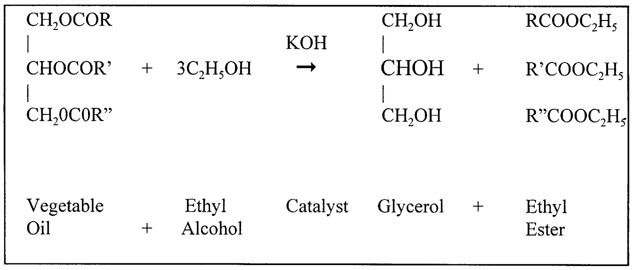

Figure 1–Vegetable oil transesterification.

Table 1. Fuel properties of biodiesel (methyl and ethyl esters of rapeseed oil and hydrogenated soy ethyl ester) in comparison to diesel

	Biodiesel			
Properties*	Ethyl Ester	Methyl Ester	HySEE	No. 2 Diesel
Heat of combustion MJ/kg (gross)	40.5	40.5	39.9	45.4
Flash point (°C)	124	179	192	74
Cloud point (°C)	–2	0	10	–12
Pour point (°C)	–10	–15	6	–16
Viscosity (cSt @ 40°C)	6.17	5.65	5.7	2.98
Sulfur (%, wt)	0.014	0.012	0.02	0.036
Specific gravity 60/60	0.876	0.880	0.874	0.850

* Ethyl ester, methyl ester, and no. 2 diesel properties are from Peterson et al., 1994. HySEE properties are based on tests performed by BAE Analytical Lab, University of Idaho, Moscow, Idaho, in September, 1997.

Vegetable oils are esters made by living plants from fatty acids and glycerol (an alcohol). Transesterification involves trading the combined glycerol of vegetable oils for a reagent alcohol in the presence of an alkaline or acidic catalyst to yield free glycerol and a combined alcohol in the form of fatty acid esters. Transesterification may be either an acidolysis, where the acid component of the ester is replaced with another acid, or an alcoholysis, where the alcohol component is replaced by a different alcohol. In this work transesterification is an alcoholysis because the glycerol of the vegetable oil is exchanged for a simple alcohol (ethanol) (see fig. 1).

The transesterification process produces a fuel which can be used in existing diesel engines with only minor modifications to the engine. The process could be used by existing agricultural enterprises. The process changes the properties of the vegetable oil to make it acceptable for diesel fuel use, particularly in direct injection diesel engines. Typical properties of Rapeseed Ethyl Ester (REE), Rapeseed Methyl Ester (RME), HySEE, and D2 are given in table 1.

Literature Review

Only a few previous long term tests with biodiesel were found in the literature. A number of demonstration projects have been conducted but most of these have not reported tear down of engines before and after the tests.

Perkins et al. (1991) reported a 1,000-h EMA engine test with three identical engines fueled with 100% Rapeseed Methyl Ester (RME), 50% RME/50% D2, and 100% D2. Engine performance, analysis of concentration of wear metals in the lubricating oil, and injector deposits were examined on these engines and RME appeared to be at least equivalent to D2.

Zhang et al. (1988) using the same engines and fuels as Perkins et al. (1991), compared two replicates of the EMA screening tests on three identical engines. The three engines were fueled with 100% RME, 50% RME/50% D2, and 100% D2. The RME fueled engine had a slight reduction of power (6% drop) with no significant difference in internal engine component wear. Fuel dilution of the engine oil was noted to be a problem in the initial 50 h, but subsequent oil analysis showed no dilution for the remaining 150 h of the test.

Ali and Hanna (1996) performed a 200-h EMA test on a Cummins N14-410 engine fueled with a blend of 80% D2, 13% beef tallow, and 7% ethanol. The engine was evaluated for performance, exhaust emissions, and heavy metals in the engine oil. While they noted the engine power was relatively constant throughout the test, the engine experienced three injector failures in 198 h due to cracks at the injector tips but were traced back to improper injector installation.

Objectives

The purpose of this study is to gain additional experience in the production of HySEE and to develop more in-depth data on the effect of the fuel on engine performance and durability. Specific objectives were:

- Study the long term effects of fueling a direct injected diesel engine with HySEE.
- Gain experience with fueling and operational difficulties associated with HySEE.

Materials and Methods

Fuel Production

The fuel used in this test was Hydrogenated Soybean oil Ethyl Ester (HySEE). It was produced in 10 batches from used french fry oil and alcohol obtained from the J. R. Simplot Company in Caldwell, Idaho. The oil was esterified using the technique developed at the University of Idaho. Approximately 9800 L (2589 gal) of french fry oil and about 1893 L (500 gal) of ethanol were required to produce 8105 L (2141 gal) of HySEE for an overall yield of about 83%.

Test Procedure

The test procedure used was five consecutive Engine Manufacturer's Association (EMA) 200-h preliminary durability screening tests for a total of 1000 h. The purpose of this test was to assess the potential impact of alternative fuels in a relatively short period of time. The standard EMA test consists of four engine load cycles over a three-hour period (1 set). Five consecutive sets (15 h) are followed by a 9-h minimum period during which the engines are shut down and allowed to reach ambient temperature. Due to staff scheduling difficulties, the EMA test was modified to include only four consecutive sets (12 h) each day.

The four engine load cycles are described as follows:

1. Rated condition (60 min): Operating at full throttle, a load was applied until the engine speed decreases to the manufacturer's specified rated speed (3000 rpm).

2. Maximum torque (60 min): Operating at full throttle, a load was applied until the engine speed decreases to the speed of rated torque as described by the manufacturer (2550 rpm).
3. High idle (30 min): The load was set at 25% of maximum torque and the throttle is varied to achieve an engine speed of 90% of rated speed (2700 rpm).
4. Low idle (30 min): At no load, the throttle was varied to achieve the manufacturer's recommended curb idle (1250 rpm).

Engines

Three freshly rebuilt Yanmar 3TN75E-S diesel engines (three-cylinder, four-stroke, naturally aspirated, direct injection) were used as test engines. The Yanmar engine specifications are listed in table 2.

Table 2. Yanmar 3TN75E-S specifications

Specification	Dimension	
Type	Four-stroke, water cooled	
Combustion system	Direct injection	
No. of cylinders	3	
Bore	75 mm	2.9528 in.
Stroke	75 mm	2.9528 in.
Displacement	994 cc	60.7 in.^{3}
Compression ratio	17.6:1	
1-h power rating (3000 rpm)	15 kW	20 hp

Test Cells

The tests were performed on the three engines simultaneously. Three computer controlled test cells were used. The test cells were equipped with a hydraulic dynamometer consisting of a Hydreco gear pump which was cradled for torque measurement and coupled directly to the engine clutch shaft. A Sperry-Vickers electronically modulated relief valve was used to control the hydraulic pump pressure and thus the load on the engine. A constant volume flowmeter, which uses elapsed time for a known volume of fuel to be consumed, and a magnetic pickup that measures engine speed at the clutch shaft were also included on each test cell. Rack position was controlled by a DC gear head motor linked to the fuel pump.

Each test cell was continuously monitored and controlled from a data acquisition and control system (Hewlett-Packard 3497 connected to a PC). The system capabilities include control of engine speed and load as well as measurement of engine torque, speed, power output, fuel consumption, crankcase oil temperature, exhaust gas temperature, fuel temperature, hydraulic load unit oil temperature, and ambient air temperature.

Fuel Heating

Because of safety issues in storing diesel fuel in the test facility, an external fuel shed was set up to house the fuel tanks. Since this test took place largely during the winter months, low ambient temperatures required the use of both tank heaters and line heaters to keep the fuel from crystallizing and plugging filters. The heating system for the outside fuel shed consisted of hot water flowing through rubber hoses in parallel with the fuel lines and finally through heat exchangers in the shed. The water in the heating system was recycled in a closed loop. The heating system was capable of keeping the fuel at 20°C (68°F) or above, in most cases.

Oil Analysis

Analysis of lubrication oil contaminant content has shown in the past to be an excellent indication of internal engine conditions. Many mechanical and wear problems show up as excessive metal contamination in the lube oil before they can be visually or audibly detected by the operator. For this test, lubrication oil was analyzed for contamination at 100-h intervals by Chevron LubeWatch (Spokane, Wash.).

Torque Tests

At 0 h and at each 200-h interval, the engines were dynamometer tested. Injectors were tested for proper spray pattern and pressure using a Keine DT1300 diesel injector tester. A portable opacity meter (Telonic-Berkley, model 200) interfaced to the data acquisition system was used to measure smoke opacity during the torque tests. Compression tests were performed on each engine using a Snap-On Model MT33B compression tester.

Results and Discussion

Power and Fuel Consumption

Relative power for each engine over the course of the test is presented in figure 2. Power at 2950 rpm stayed relatively constant for each engine for the entire 1000 h. The sudden drop at 800 h for the 50% HySEE engine is likely an instrumentation error. Figure 3 shows the fuel consumption for each engine over the course of the test. The engine fueled with 100% HySEE had less power and used less fuel than the other two engines. The 50% HySEE fueled engine ranked second highest power and fuel consumption, and the 25% HySEE engine produced the most power and consumed the most fuel. Total fuel consumption was lowest for the 50% HySEE engine. Figure 4 shows the brake specific fuel consumption at each 200-h interval.

At the conclusion of the test, the fuel pumps were re-calibrated and the 25% HySEE engine was found to have a mis-calibrated fuel pump which supplied excess fuel at

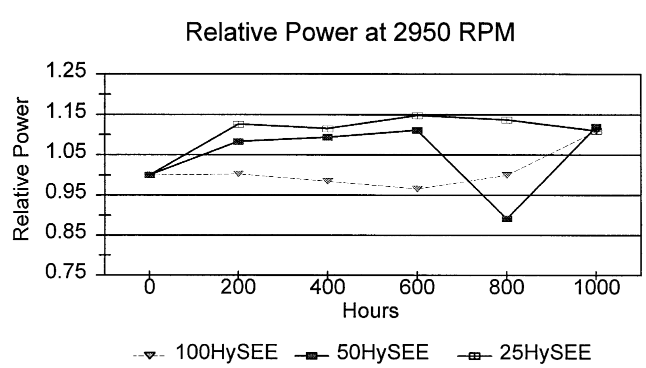

Figure 2–Relative power at 2950 rpm for HySEE and HySEE blends for a 1000-h durability test.

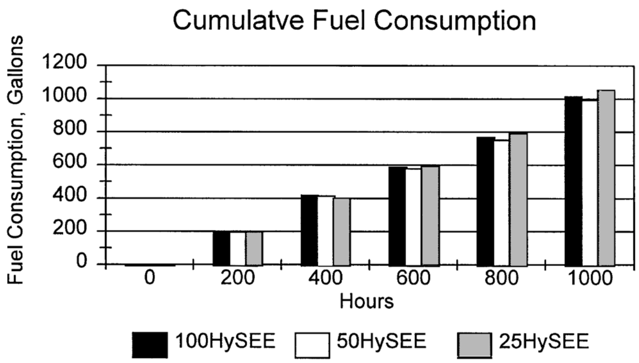

Figure 3–Cumulative fuel consumption at 200 h intervals for HySEE and HySEE blends for a 1000 h durability test.

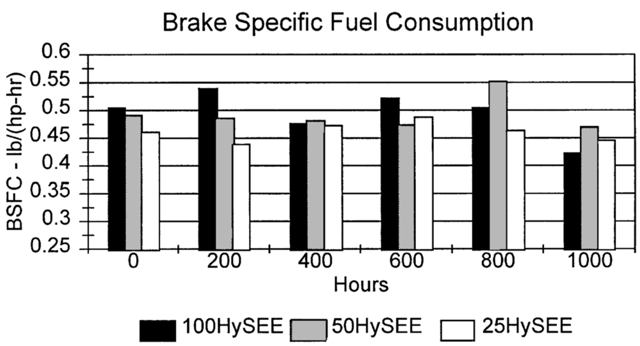

Figure 4–Brake specific fuel consumption at 200-h intervals for HySEE and HySEE blends for a 1000-h durability test.

maximum rack settings. This caused excessive smoke and increased power when the engine was operated at full load.

Fuel Characterization

Fuel quality and characterization tests were performed by two independent labs. Systems Labs Services (Kansas City, Kans.) performed the mono-, di-, and triglycerides, free glycerin, and total glycerin analysis using the Austrian method developed by Plank (1994.) Phoenix Chemical Labs (Chicago, Ill.) performed the remainder of the fuel characterization tests. Fuel characterization data appears in table 3.

Table 3. Fuel characterization

Fuel specific properties	25% HySEE	50% HySEE	100% HySEE
Specific gravity, 60/60	0.852	0.860	0.874
Viscosity, CS @ 40°C	3.5907	4.3576	5.98
Cloud point (°C)	3	5	9
Pour point (°C)	–33	–9	6
Flash point (°C)	70	82	150
Boiling point (°C)	356	364	460
Water and sediment (% vol.)	< 0.005	< 0.005	< 0.005
Carbon residue (% mass)	0.002	0.011	0.024
Ash (% mass)	0.003	0.000	0.000
Sulfur (Wt%)	0.037	< 0.005	< 0.005
Cetane number	46.3	51.6	62.2
Heat of combustion, gross (MJ/kg)	43.952	42.568	39.961
Copper corrosion	1A	1A	1A
Particulate matter (mg/L)			
Total	0.49	0.50	1.20
Non-combustible	0.08	0.11	0.28
Elemental analysis			
Nitrogen (ppm)	97	81	63
Carbon (%)	85.23	82.65	77.11
Hydrogen (%)	12.85	12.44	12.48
Oxygen (% by difference)	1.88	4.91	10.41
Iodine number	49.1	45.8	68.9
Ester specific properties			
Percent esterified	96.37		
Acid value	0.165		
Free glycerol (%wt)	0.003		
Total glycerol (%wt)	0.673		
Monoglycerides (%wt)	1.512		
Diglycerides (%wt)	1.290		
Triglycerides (%wt)	0.826		
Alcohol content (% mass)	0.083		
Catalyst (microgram/gram)	BDL*		
Fatty acid composition (%)			
Palmitic (16:0)	10.3		
Stearic (18:0)	15.0		
Oleic (18:1)	24.6		
Linoleic (18:2)	48.6		
Linolenic (18:3)	0.0		
Eicosenoic (20:1)	0.3		
Behenic (22:0)	0.3		
Erucic (22:1)	0.0		

* Below detection limit.

Engine Oil Analysis

Engine oil analysis data is presented in figures 5 through 7 which show iron content, aluminum content, and F-soot number. At 820 h, the engine fueled with 100% HySEE lost oil pressure and was shut down by the emergency shut down system installed to protect the engine. Upon inspection, it was found that the main bearings had suddenly failed, increasing the aluminum count in the lube oil from 7 to 174 ppm as shown in figure 6. It was suspected that a sudden over-speed of the engine caused by the clutch releasing may have been the cause of the failure. There was no reason to suspect the bearing failure was caused by the fuel. The main bearings were replaced without opening the top end of the engine and the test was resumed. The oil analysis shows that the aluminum content in the lube oil returned to 8 ppm with no more difficulty during the test.

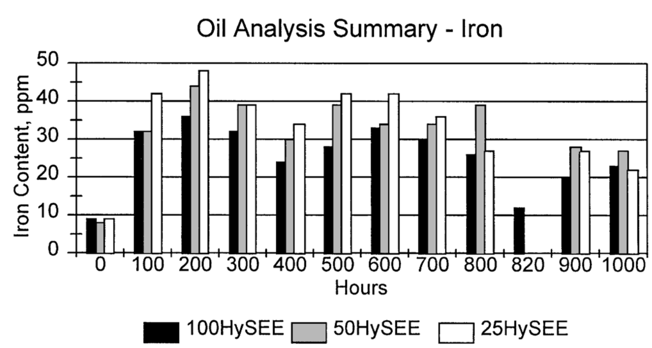

Figure 5–Iron contamination in the engine oil for HySEE and HySEE blends for a 1000-h durability test.

Engine Compression and Injector Pressures

Compression and injector pressure, measured at each 200 h remained relatively constant throughout the test. One measurement on the 100% HySEE engine at 200 h showed a low cylinder. The compression test tool was suspected of being defective and it was replaced. Subsequent tests showed normal compression and indicated that the low reading was due to failure of the tool. The compression readings and injector pressures over the course of the test are shown in figure 8 and 9.

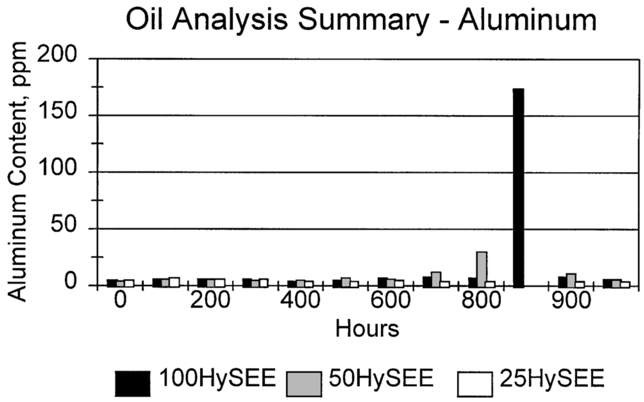

Figure 6–Aluminum contamination in the engine oil for HySEE and HySEE blends for a 1000-h durability test.

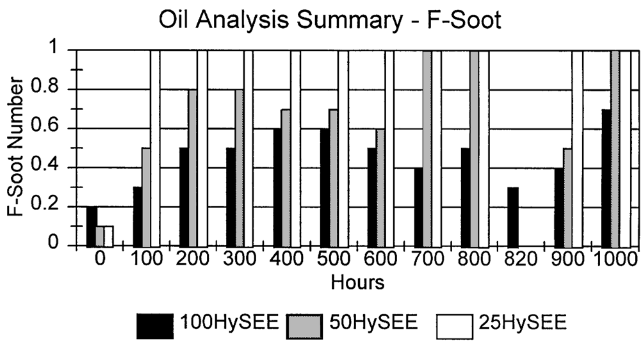

Figure 7–F-soot number at 100 h intervals for HySEE and HySEE blends for a 1000-h durability test.

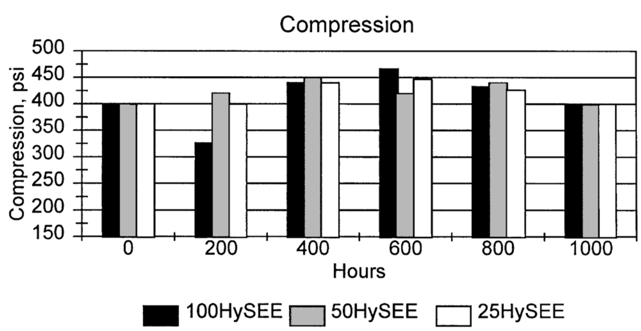

Figure 8–Engine compression at 200-h intervals for HySEE and HySEE blends for a 1000-h durability test.

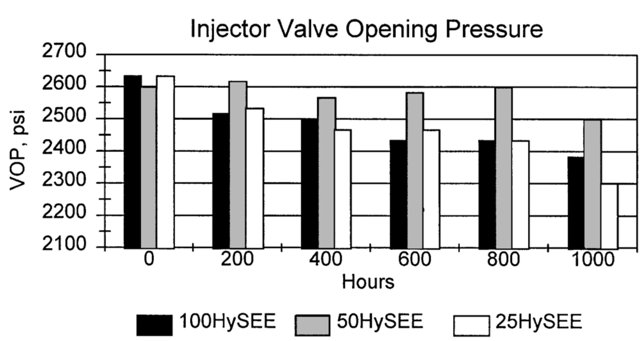

Figure 9–Injector valve opening pressures at 200-h intervals for HySEE and HySEE blends for a 1000-h durability test. Each bar is the average of three cylinders.

Soot

After the engines were disassembled, there was an obvious difference in the amount of black deposits inside each engine. Upon initial inspection, these deposits appeared to be soot. The 100% HySEE engine had little or no black soot visible in the oil pan, valve cover, or inside the case. In contrast, the 50% HySEE engine had more visible soot while the 25% HySEE engine clearly had the most. The oil analysis reports shown in figure 7 verify this trend. The reported F-Soot number in figure 7 roughly corresponded to the blend of HySEE in each engine. The 25% HySEE had the largest F-Soot number, while the 100% HySEE consistently had the lowest. It should be noted that the fuel setting on the 25% HySEE engine was found to be out of range after the test and more fuel was injected into this engine than the others. This would have caused more incomplete combustion than the other two engines and thus more soot. It should also be noted that the trend from low soot to high soot did follow the trend from more biodiesel to less biodiesel for the three engines. Therefore, over-fueling was not totally responsible for the higher soot, but probably made it worse.

Smoke

During the tests, the University of Idaho Safety Office raised concern about the amount of smoke emitted from the test cells exhaust stack when all three engines were on the maximum torque part of the EMA cycle. The Safety Office stated that the amount of smoke (based on opacity) being emitted during this part of the cycle exceeded the amount allowed for stationary engines. The maximum torque part of the cycle lasts a combined 3 h each day. In an effort to comply with the UI Safety Office's request to reduce the smoke, a dry filter was applied to the stack to attempt to capture some of the soot particles before they were released to the air. This method failed due to the extreme temperature of the exhaust gas and the filter subsequently burned. The second method was more successful. A water spray nozzle was installed in the stack to precipitate some of the soot particles in water droplets and collect them as a slurry in a drain port on the stack. This method produced the required reduction in smoke from the stack during these cycles. This form of air pollution control was used only on the maximum torque part of the cycle to conserve water and reduce the amount of slurry drained off. All other parts of the cycle achieved acceptable levels of smoke without the use of the pollution control device.

Fuel Filter Plugging

Low ambient temperatures during the middle of winter caused some filters to plug even with the heated fuel system. The existing fuel heating system could not apply enough heat to the fuel shed during the coldest days. This posed a problem since HySEE is more vulnerable to the cold than other biodiesel fuels due to its high cloud point. At fuel temperatures below 25°C (77°F), the higher molecular weight esters in HySEE would start to crystallize and settle to the bottom of the tanks. Since the fuel was drawn off near the bottom of the tanks, filters began to plug. This problem was alleviated by placing additional thermostatically controlled band heaters under tanks and a small band heater around the 100% HySEE filter.

Bypass Valve on Fuel Filter

Toward the end of the test, the 25% HySEE engine began to quit at the beginning of the maximum torque cycle. The engine could be restarted to complete the test. This problem was intermittent for a couple of days. After thorough investigation, the bypass valve on the fuel filter housing was found to be defective. An in-line fuel filter was installed and the existing filter bypassed so the test could be completed.

Running Cold

The 100% HySEE engine overheated once and started running cold after that. The problem was due to a defective thermostatic fan switch. The original fan switches were a universal type adjustable switch which had been unreliable in the past. In an effort to solve the problem permanently, an automotive-type sealed fan switch was installed on each engine to replace the troublesome adjustable limit switches.

Main Bearing Failure

At 820 h, the 100% HySEE engine experienced main bearing failure and started shutting down due to low oil pressure. This failure was thought to be due to the clutch becoming disengaged while the engine was running at full torque. The resulting overspeed compounded by an imbalance of the flywheel/clutch system caused the excessive wear in the two rearmost main bearings. At the time of the failure, all the main bearings were replaced and the engine was put back in the test cell to finish the test. The engine completed the test without further difficulty. For the record, an extra oil analysis was taken at this time in the failed engine only. Looking at the oil analysis of aluminum content for this engine in figure 6, it is obvious by the increased level of aluminum that a bearing had failed. It is unlikely that this problem was fuel related.

Engine Tear-down

At 1000 h each of the engines were disassembled for observation of engine components. The most noticeable comparison was the relative cleanliness of the internal components such as interior of valve covers, oil pans, rocker arm assemblies and similar components. With the 100% HySEE engine these components were relatively clean, with the engine operated on 25% HySEE these

Figure 11–Pistons showing the relative amount of staining and deposits. From left to right are 100% HySEE, 50% HySEE, and 25% HySEE.

components were extremely black and covered with soot filled oil. The 50% HySEE fueled engine components were neither as clean as the 100% HySEE nor as dirty as the 25% HySEE fueled engine. Figure 10 is a photograph of the oil pans and figure 11 a photograph of the pistons. Each of these show the relative cleanliness of the engines. Figure 11 shows the degree of staining and relative amount of deposits on the pistons resulting from each fuel. It should be noted that this was in agreement with the oil analyses soot measurement and may have been accentuated by over fueling of the 25% engine although the 50% HySEE fueled engine did show the same relative effect. Other tear down observations were as follows:

The 100% HySEE-fueled Engine. Ring grooves were clean. Pistons were bright very little tarnish. There was some soot in the combustion chamber as seen in figure 12. Injectors were covered with a relative thin layer of hard deposit. Crankshafts did not need to be turned, cylinders were honed, but not bored for rebuild.

The 50% HySEE-fueled Engine. Ring grooves not as clean as 100% HySEE-fueled engine. Pistons showed more staining and had more deposits. Some deposits were on the injectors and head, but they were softer and easier to remove than for the 100% HySEE-fueled engine (fig. 13). The crankshaft did not need to be turned, cylinders were honed, but were not bored for the rebuild.

Figure 10–Oil pans showing the relative amount of soot present in each engine. From left to right are 100% HySEE, 50% HySEE, 25% HySEE.

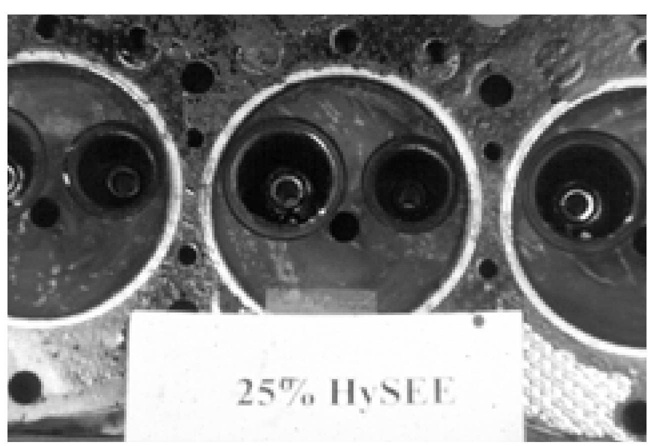

Figure 12–Head from engine fueled with 25% HySEE.

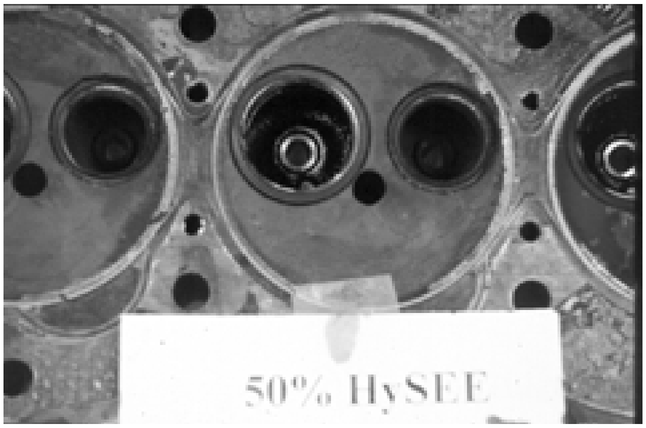

Figure 13–Head from engine fueled with 50% HySEE.

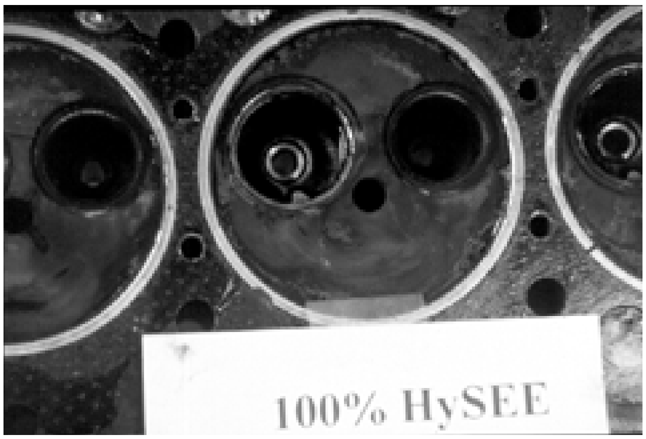

Figure 14–Head from engine fueled with 100% HySEE.

The 25% HySEE-fueled Engine. Ring grooves contained some black deposits but rings were free, pistons were badly stained black, and had soot deposits. Deposits on the injectors and head were softer and easier to remove than for either of the other engines. The head is shown in figure 14. The crankshaft did not need to be turned, cylinders were honed, but were not bored for the rebuild.

All components for all engines were within rebuild specifications. New rod and main bearings were installed on all engines. Crankshafts, cam shafts, and rocker arms were all within rebuild specifications.

POST-TEST INJECTOR PUMP EVALUATION

At the end of the 1000-h test, the injector pumps were sent to Spokane Diesel Pump Repair, Inc. for evaluation. A summary of this evaluation with pump delivery reported in cubic centimeters per 1000 strokes, is shown in figure 15. They found that by the end of the test the 25% HySEE engine's injector pump was over-fueling the engine during high torque operation (1100 rpm) by nearly 25%. This evaluation should be considered in conjunction with cumulative fuel consumption data shown in figure 3. Figure 3 shows a slight increase in fuel consumption in the 25% HySEE engine, but the increased soot and smoke were not due solely to this over-fueling.

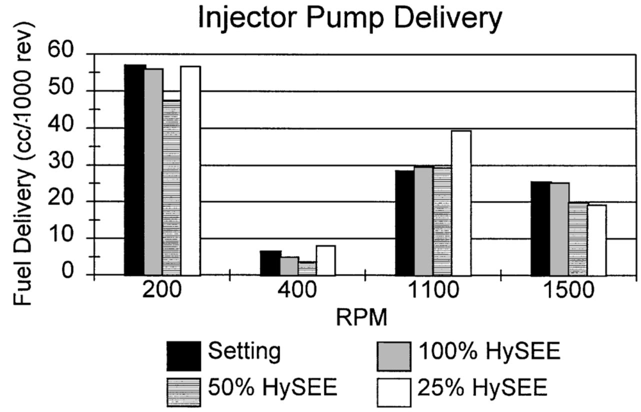

Figure 15–Post test injector pump evaluation. Setting refers to the pump specification flow rate.

SUMMARY AND CONCLUSIONS

For this test over 7571 L (2000 gal) of biodiesel from hydrogenated waste vegetable oil was produced and used in 1000-h engine tests with a 5X EMA test cycle. Fuels tested were 100% HySEE, 50% HySEE, and 25% HySEE. Fuel production of HySEE, using the University of Idaho Department of Biological and Agricultural Engineering process, produced a fuel with total glycerol in the range of 0.3% to 0.8%. Recovery of ester from the fuel with this process was about 80% compared to nearly 100% with virgin oils. Fuel characterization data show that HySEE has some properties such as flash point and cetane number that are improvements over diesel and some properties, particularly pour point that is less desirable than diesel. No short term engine performance data was developed for this project, however, earlier experiments showed that engine power is reduced about 5% and fuel consumption increased by about 7% when compared with the same engine using D-2 diesel fuel (Peterson et al., 1994). Other specific conclusions of this study were as follows:

1. HySEE performed adequately compared to diesel fuel. However cold weather operation was a continual challenge resulting in filter plugging and a need for extraordinary effort to heat fuel lines and the fuel filters since the fuel storage was outside and away from the building where the engine tests were conducted.
2. At each of the normal oil change intervals, oil analysis results for wear metals for the 100% HySEE engine were equal to or better than either the 25% HySEE or the 50% HySEE fueled engine.
3. Engine injector pressure and compression was essentially unchanged for all engines over the course of the 1000 h.
4. The engine fueled with 100% HySEE was cleaner and brighter internally than either the 25% HySEE or the 50% HySEE fueled engine.
5. The 25% HySEE fueled engine was overfueled in the torque range according to a post injector pump test.

RECOMMENDATIONS.

Used vegetable oil has potential for use as a fuel in diesel engines. Results presented in this article suggest that more testing is warranted. The used hydrogenated oils used in these tests has a high cloud point and thus would require special handling in cold climates. Additional items to be considered are the following: testing in large engines; emissions tests; biodegradability tests; toxicity tests; determination of variability in used oils, especially trap greases, that might give cause for variation in properties or compounds that would change the results reported here.

One attempting to reproduce this chemical reaction should be trained in the handling of chemicals, use of proper personal protective equipment, and to take adequate safety precautions to prevent fires.

Biodiesel is subject to state and federal road taxes, even if it is produced at home from your own materials. Anyone using biodiesel in an on-road application should check with the state tax commission and the internal revenue service for proper payment of applicable state and federal taxes.

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