☘A Rapid Engine Test to Measure Injector Fouling in Diesel Engines Using Vegetable Oil Fuels

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ABSTRACT

Short engine tests were used to determine the rate of carbon deposition on direct injection diesel nozzles. Winter rape, high-oleic and high-linoleic safflower blends with 50% diesel were tested for carbon deposit and compared to that with D-2 Diesel Control Fuel. Deposits were greatest with the most unsaturated fuel, high-linoleic safflower, and least with winter rape. All vegetable oil blends developed power similar to diesel fueled engines with a 6 to 8% greater fuel consumption.

INTRODUCTION

Pure vegetable oils are too viscous for prolonged use as diesel fuels. Viscosity can be reduced by blending vegetable oils with less viscous fuels or by esterification of vegetable oils. The most obvious problem in a short term engine test with vegetable oil blends is the formation of carbon deposits on the injector nozzles. The amount of the deposits (coking) increased in amount with the percentage of oil in the fuel blend (1). The deposits were harder than the usual deposits formed with diesel fuels. Pictures taken under high magnification revealed the fact that deposits formed craters around the nozzle orifices (1).

Other problems in the use of vegetable oils are the result of incomplete combustion resulting in carbon buildup within the combustion chamber and rings, and contamination of lubricating oil. The problem of combustion chamber deposits and ring sticking is more severe with vegetable oil blends than with esters. This appears to be the result of the tendency of triglycerides to polymerize within the combustion chamber (2,3). The objective of this study was to use the short term engine torque test procedure developed by Wagner and Peterson (4,5) to develop a comparative test of injector coking with vegetable oil blends.

ENGINE TEST PROCEDURE

Tests were run on a John Deere T4239 four-cylinder Industrial Diesel Engine with Roosamaster pencil type direct injection nozzles (John Deere part #AR90023). The load unit was a General Electric cradle type dynamometer. The fuels used were 50% high-oleic safflower (California Fats & Oils, Inc., Richmond, California)/50% D-2 Diesel Control Fuel (Phillips Chemical Co., Bartlesville, Oklahoma); 50% high-linoleic safflower (California Fats & Oils, Inc.)/50% Diesel, 50% winter rape/50% Diesel, and 100% Diesel. The fuels were mixed at volumetric equivalents. Winter rape oil was processed at the University of Idaho and filtered through a three-stage filter unit consisting of a recleanable pre-filter, 20 μm and 4-5 μm filters (6).

The engine was warmed up for approximately 10 min on D-2 Diesel Control Fuel. At this point the test fuel was introduced during 10-min periods of running at 2500, 2300, 2100, 1900, 1700 and 1500 revolutions per min (rpm) at maximum power. The engine was run at full throttle with the speed (rpm) controlled by increasing the dynamometer loading. During the runs, ambient air, crankcase oil, exhaust turbo inlet and exit temperatures were recorded at two-min intervals. After completion of the 1500 rpm run, the engine was unloaded and cooled down on D-2 diesel for approximately 10 min. The injectors were then pulled and photographed for analysis of deposits. A clean set of injectors was reinstalled for each test.

After each run, the four injectors were photographed at a magnification of 16X at two different orientations and enlarged to 20.3 x 25.4 cm. The area of the injector silhouette was determined by tracing the silhouette outline with an electronic graphics calculator (Humonics Corp., North Wales, Pennsylvania) and calculating the area with a Wang System 220 microcomputer. Injector areas of the test fuels (incremental injector areas) were expressed as the difference in area relative to the average injector area for 37 injector area measurements with D-2 diesel fuel. Engine tests were run with a random ordering of the four fuels tested. Three replicate runs were made for each fuel tested.

Fatty acid compositions (Table I) were determined by conversion of oils to methyl esters (7) and separation of esters in a 6-ft, 1/8-inch O.D. stainless steel column packed with 10% Silar 10C on 100/120 Gas Chrom Q at 180 C in a Varian 1400 gas chromatograph. Viscosities were measured with Cannon-Fenske viscometers at 37.8 C (100 F).

RESULTS AND DISCUSSION

All injectors exhibited deposits in a crater-like manner on the outside tip, especially around the orifices. All deposits were hard, and their removal required scraping. The data from injector photographs were analyzed by analysis of variance to determine the effects of fuel type on the area of injector deposits. The results are summarized in Table II.

All vegetable oil fuel blends gave a statistically significant (significance level, $\alpha < 0.05$) increase in carbon deposits relative to diesel. This seemed clear from an examination of

TABLE I

Vegetable Oils Used in the Tests

Properties	Winter rape	Oleic safflower	Linoleic safflower
Fatty acid composition (% b.w.)			
Palmitic	3.0	4.8	5.9
Stearic	1.1	1.4	1.5
Oleic	18.4	74.1	8.8
Linoleic	14.8	19.7	83.8
Linolenic	7.1	–	–
Eicosenoic	10.5	–	–
Erucic	45.1	–	–
Viscosity (mm^2/s)	48.4	39.1	30.7
Iodine value[a]	101	98	153

[a]Calculated from fatty acid compositions using iodine number of triglycerides from ref. 8.

TABLE II

Effect of Fuel Composition on Injector Coking

Fuel	Incremental injector area relative to diesel (cm^2)	No. of photographs
50% Winter rape	3.93	56
50% Oleic safflower	5.01	55
50% Linoleic safflower	7.57	48

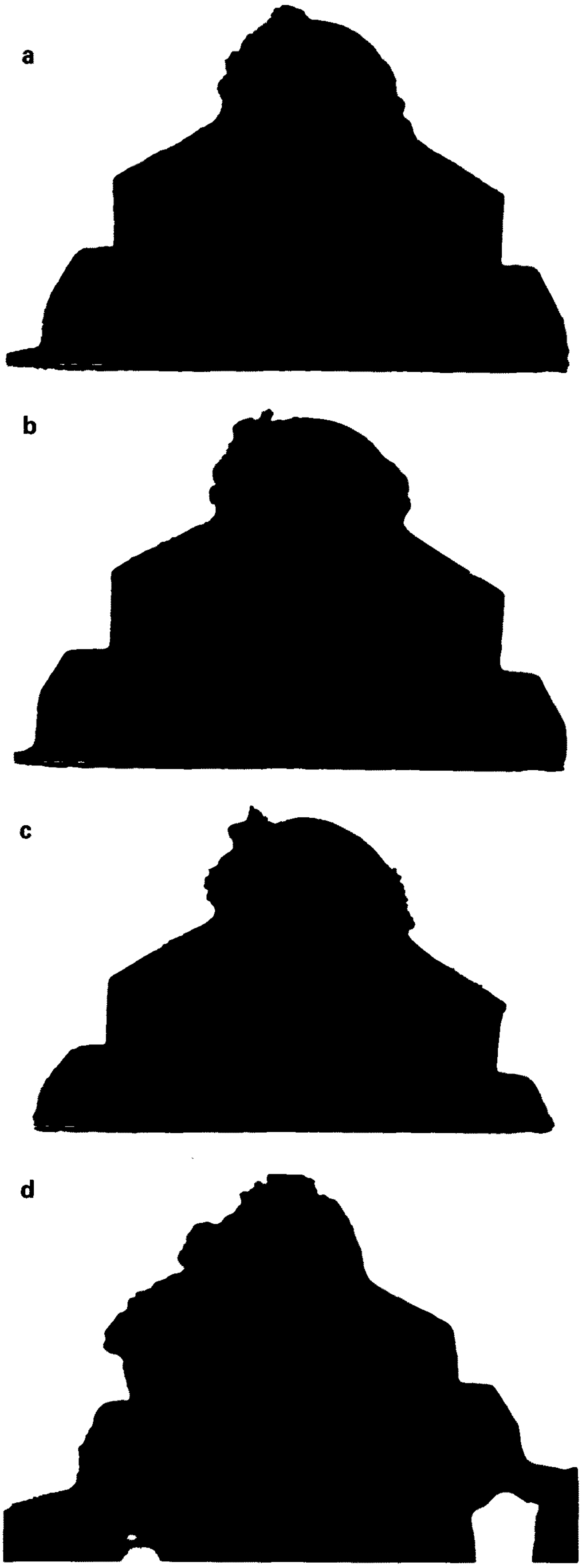

FIG. 1. Injector silhouettes obtained after high load engine tests. a. 100% diesel; b. 50% winter rape; c. 50% oleic safflower; d. 50% linoleic safflower.

the injector photos (Fig. 1) where diesel injectors were relatively clean while the other fuels showed significant deposits. Statistical analysis showed that the high-linoleic safflower fuel gave significantly more ($\alpha < 0.1$) deposits than either the high-oleic safflower or winter rape fuels. This can be attributed to the greater unsaturation of linoleic safflower (Table I). The oleic safflower fuel blend gave slightly greater coking than the winter rape blend (Table II, $\alpha < 0.2$). These two fuels are relatively saturated (Table I and II). The slightly higher iodine value and higher viscosity of winter rape relative to oleic safflower would indicate a higher potential for injector coking with winter rape. However, this was not observed, and the winter rape blend gave the least coking for the fuel blends tested. The lowest viscosity vegetable oil, linoleic safflower, gave the greatest coking, indicating that the degree of saturation is a significant factor in determining fuel performance.

The initial power measurements for the vegetable oil-diesel blends at 2500 rpm were similar and averaged 2.5% greater than the 82.2 HP developed by the 100% diesel fueled engine at 2500 rpm. As the engine loading was increased, the power developed by all fuels was similar. At 1500 rpm all fuels produced 59.4 HP. The vegetable oil-diesel blends had similar rates of fuel consumption. At 2500 rpm diesel fuel was consumed at the rate of 17.6 kg/hr, 8% greater than diesel. At 1500 rpm the rates of fuel consumption were 12.2 kg/hr for diesel and 12.9 kg/hr for the vegetable oil blends, an increase of 6% for the blends.

In long term engine tests (4) with 100% linoleic safflower oil (two 830-hr tests) and 70% winter rape/30% No. 1 diesel with Dupont FOA-2 dispersant additive (850 hr), the wear rate for the safflower-fueled engine was approximately twice that of the diesel fueled engine. The safflower-fueled engine showed more carbon in the combustion chambers and additional varnish and carbon build-up on the injector nozzle. The winter rape blend was clearly superior to the linoleic safflower as a fuel. The 70/30 blend of winter rape and diesel successfully powered a single-cylinder diesel engine for 850 hr with no sign of adverse wear, lubricating oil contamination or reduction in power output (4).

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