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Safflower Seed Oil of Turkish Origin as a Diesel Fuel Alternative

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ABSTRACT

Among the biomass resources, vegetable oils seem to have the potential to be used as fuel alternatives for diesel engines. The major restricting factor in the direct use of vegetable oils in diesel engines is their high viscosity, which causes serious problems in fuel-injection systems of modern CI engines that are sensitive to viscosity changes. In this study, the dilution technique for viscosity reduction was applied, and blend fuels were prepared by adding 10–90% by volume safflower seed oil of Turkish origin to commercial Grade No. 2-D diesel fuel. Variations in viscosity with temperature of the blend fuels were determined, ASTM fuel property tests were performed, and the 20% blend having fuel properties close to the limits specified for Grade No. 2-D diesel fuel was selected for further investigation. Engine performance tests and exhaust emission values gave promising results with the 20% blend fuel (20% by volume Dinçer Safflower seed oil, 80% by volume Grade No. 2-D diesel fuel).

Index Entries: Safflower seed oil; viscosity; blend fuel; engine performance; exhaust emissions.

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INTRODUCTION

The search for fuel alternatives originates from the fact that present sources of fossil-derived fuels are finite, and their supplies will be exhausted and diminish gradually by the end of this century. There is therefore an extensive search for new energy sources, among which biomass energy is given special attention and considered as an attractive alternative to conventional energy sources. Vegetable oils in particular have an exceptional importance within the biomass sources, since they had been used as fuel alternatives in diesel engines by the inventor of the engine R. Diesel as early as 1892. However, the ready availability of inexpensive petroleum-derived diesel fuel provided little incentive for experimenting with alternative renewable fuels for diesel engines. It was after the two consecutive OPEC oil embargo followed by fuel shortages and rapidly increasing fuel prices that the international interest was directed toward liquid fuels of renewable origin. Liquid fuels are a vital necessity, particularly for the continuation of agricultural production, which mostly depends on diesel fuel. Timing of the field operations, such as planting, cultivating, and harvesting, is especially critical. For all of these operations, a readily available supply of liquid fuel is essential, and vegetable oil-based fuels seem to be a convenient solution should an emergency occur. Substitution of petroleum-based diesel fuels with vegetable-oil-based fuel alternatives requires the establishment of an integrated system that involves the production, processing, and end use of the new fuels on a dual-technology strategy. The oil crop selected must be a valuable oil export crop and must be easily cultivated. It should also be readily turned into liquid fuel according to demand changes. The equipment used for processing oil for the food and export markets should also serve as the production equipment for fuel alternatives at times of crisis and emergency. Such a biomass-based technology when administered properly is important, especially for the developing countries with rich agricultural potential (*1-3*). Türkiye is a developing country and 90% of the crude petroleum consumed is provided through imports that are a heavy burden on the country's agriculture-based economy. Like most of the developing countries, Türkiye is endowed with rich biomass resources; with the completion of the Southeast Anatolia Project, 1.6 million hectars of arid land will be irrigated, and the oil crop production is estimated to increase by 73% (*4,5*). Proper selection of the oil crop for the area can easily create a valuable source for vegetable-oil-based liquid fuel production. Evaluation of such a renewable energy source seems to be the appropriate option that can help solve the necessity of petroleum importation of the country in the future.

Vegetable oils have heat contents that are approx 90% of that of diesel fuel, but their high viscosity is a major restriction in their direct use in diesel engines. High viscosity causes durability problems in the engine. Poor atomization of the fuel, formation of deposits on the tip of the injection nozzles and on the piston surface, and contamination of the lubricating oil with unburnt residues are the observed handicaps. The high viscosity problem is approached by four techniques: dilution, microemulsification, pyrolysis, and transesterification. In the dilution technique, fuel alternatives are prepared by adding a certain amount of chemically convenient vegetable oil to diesel fuel. The difference in the chemical structure of vegetable oils from Grade No. 2-D diesel fuel is another factor that causes durability problems in the engine. Oils containing fewer points of unsaturation in their component fatty acid structure have less tendency to undergo both oxidative and thermal polymerization reactions during storage and combustion. Oxidative polymerization, being the mechanism of storage deterioration, occurs by the interaction of double bonds and oxygen to form peroxides. Thermal polymerization takes place either by Diels-Alder mechanism or a free radical mechanism under combustion conditions. So a vegetable oil selected for stability in storage will also help reduce combustion problems (*1,6–8*). There are different opinions about the maximum tolerable amount of vegetable oil in diesel fuel that can safely be used in the diesel engines and about the chemical composition of the vegetable oil that is going to be blended. According to some researchers, long-term operation of the field tractors and trucks running on 20% vegetable oil (sunflower, soybean, coconut) 80% diesel fuel blends was completed without any problems, whereas operation with 50% blend fuels resulted in the contamination of crankcase oil with unburnt residues (*1,6,9–11*). Although using 25% sunflower oil–75% diesel fuel blend was only recommended under emergency conditions by some researchers, the same blend prepared with a less unsaturated vegetable oil was reported to pass the 200-h Engine Manufacturers' Association (EMA) test (*1,6,12*).

This study is an investigation of the possibilities of using the oil extracted from a variety of safflower seeds cultivated in Türkiye as a diesel fuel extender. Safflower can be cultivated in the same manner and processed using the same equipment as sunflower. However, although sunflower is one of the basic raw materials of the edible oil industry, safflower is an oilseed of minor importance for the same industry in Türkiye. It is cultivated in the Central Anatolia and Thrace regions of the country within the scope of certain projects that are supported by the Ministry of Agriculture and Forestry. The fatty acid composition of the oil is found to be suitable for use as an engine fuel. Therefore, the blends prepared using safflower oil–diesel fuel have been studied for their fuel properties, and the convenient blend was tested for its performance in the CI engine.

EXPERIMENTAL WORK AND RESULTS

Crude safflower oil used in the experiments was extracted from the "Dincer" variety of safflower seed that is grown in the Thrace region of

Table 1
Technological Characteristics
of Dinçer Safflower Seed and Oil

Seed characteristics		
Average weight (10^{-5} kg)		3.8
Average length (10^{-3} m)		6.6
Average husk content (wt%)		46.0
Moisture content (wt%)		8.1
Oil content (dry basis, wt%)		28.9
Fat characteristics		
Density at 293 K (kg/m^3)		925.4
Refractive index at 293 K		1.4763
Acid value (mg KOH/g)		4.4
Saponification value (mg KOH/g)		188.1
Iodine value		
Hanus method (g I_2/100 g)		101.2
Wijs method (g I_2/100 g)		99.6
Unsaponifiable matter (wt%)		0.9
Fatty acid distribution (wt%)		
Palmitic	16:0	23.1
Stearic	18:0	9.7
Oleic	18:1	28.4
Linoleic	18:2	36.6
Linolenic	18:3	2.2
Calculated mean molecular wt of the oil (kg/mol kg)		833.3

Türkiye by mechanical cold press extraction in an oilseed processing factory, Trakya Sanayi A.Ş. Çorlu. The technological characteristics of the seed itself and of the oil were determined according to standard methods of fat and oil analysis (*13,14*). The fatty acid composition of the oil was determined using United Technologies Packard Model 437A gas chromatograph fitted with a hydrogen flame detector and a stainless-steel column (2 m×5 mm) packed with 10% DEGS on Chromosorb W. The column temperature was 150–190°C, and the flow rate of the carrier gas, nitrogen, was 25 mL/min. Technological characteristics of the seed, oil, and the fatty acid composition are summarized in Table 1. Dinçer safflower oil has higher palmitic and stearic acid contents than those given in the literature, whereas its oleic and linoleic acid contents are very close. Oils containing less double and triple bonds in their fatty acids proved to have less tendency to polymerize. Thermal polymerization is thought to be the dominant gum-forming reaction under combustion conditions, and once formed, these gums escape complete combustion, which results in the formation of carbon deposits at the tip of the injectors. They

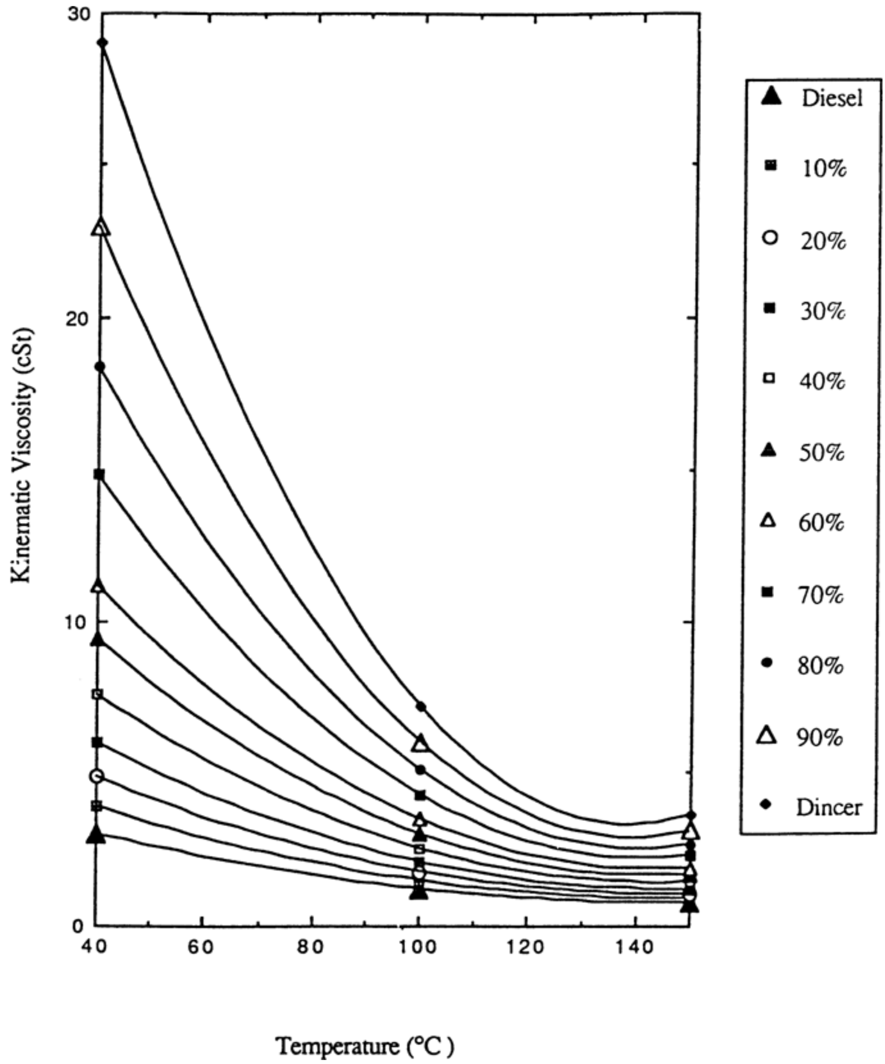


Fig. 1. Variation of viscosity with temperature for Dincer safflower oil, diesel fuel, and blend fuels.

also contaminate the lubricating oil, leading to its deterioration (*7,9*). Therefore, Dinçer safflower seed oil seemed to have a suitable fatty acid composition that would avoid the above-mentioned problems during combustion.

Applying the dilution technique for viscosity reduction, blend fuels were prepared by adding 10–90% by volume Dinçer safflower oil to Esso, Grade No. 2-D commercial diesel fuel. The variations in viscosity with temperature of the blend fuels, Dinçer safflower seed oil, and Grade No. 2-D diesel fuel are compared in Fig. 1. Evaluation of the results according to ASTM D975-90 and ASTM D445 diesel fuel specifications showed that only 10 and 20% blend fuels had kinematic viscosity values, which were within the limits specified for Grade No. 2-D diesel fuel. Other fuel properties of the blend fuels, Dinçer safflower oil, and Grade No. 2-D diesel fuel are given in Table 2. In the cetane number measurement tests, 20% blend fuel operated smoothly in the CFR test engine and had a cetane number similar to that of the reference diesel fuel, whereas with the blend fuels containing over 40% Dinçer safflower seed oil, the engine cycle-to-cycle operation was erratic and the injector showed deposits on the outside tip. Among the blend fuels, the 20% blend seemed to have fuel properties that were very close to the reference Grade No. 2-D diesel fuel, and therefore could be used like Grade No. 2-D diesel fuel in all automotive, high-speed diesel engines, in engines not requiring the higher volatility or other properties of Grade No. 1-D, and in high-speed (1200 rpm and up) marine diesel engines (*15*). Engine tests using the reference diesel fuel and the blend fuel were performed on an Acadia-Hercules Model AD-20 four-cylinder marine-type diesel engine whose specifications are listed in Table 3. Fuel consumption was measured with a Mettler PS 15 balance accurate to 0.001 kg, and engine load was dissipated using a Heenan & Froude hydraulic dynamometer. Engine and dynamometer speeds were measured with a digital tachometer. Tests for the blend fuel were performed at engine speeds of 1200, 1600, 1800, and 2200 rpm at half and full load conditions, whereas tests with diesel fuel were conducted at the same load conditions and at engine speeds of 1200, 1400, 1600, 1800, 2000, and 2200 rpm. In the beginning of each test, the engine was warmed up with the fuel to be tested for about 20 min until the engine temperatures stabilized. Taking the half- and full-load conditions as parameters, fuel consumption, dynamometer force, barometric pressure, and inlet air temperature were recorded at each engine speed. Inlet air temperatures were measured with a type T (copper-constantan) thermocouple. Figures 2, 3, 4, 5, and 6 permit comparison of engine performance on 20% blend fuel with performance on Grade No. 2-D diesel fuel. A slight decrease in power, torque, brake mean effective pressure, and brake thermal efficiency, and an increase in brake-specific fuel consumption were observed with the blend fuel at half-load condition; similarly, a slight increase in the brake-specific fuel consumption was observed with the blend fuel at full-load condition, whereas power, torque, brake mean effective pressure, and brake thermal efficiency were very close to those obtained with the reference diesel fuel. The gross heating value of 20% blend fuel is approx 2.5% lower than that of Grade No. 2-D diesel fuel; therefore, while using the blend fuel, similar engine performance characteristics with the reference diesel fuel at the same load and engine speed conditions could only be achieved with an increase in the specific fuel consumption.

Table 2
Fuel Properties of Diesel Fuel, Dinçer Safflower Oil, and Blend Fuels

Fuel type	Relative density 15.56°C/15.56°C D4052[a]	Refractive index 20°C D1218[a]	Hydrogen content, w%, D3701[a]	Surface tension 25°C, mN/m, D971[a]	Cetane number, measured, D613[a]	Gross heating value, MJ/kg, D240[a]	Flash point, °C, D93[a]	Pour point, °C, D97[a]	Sulfur content, w%, D4294[a]	Copper corrosion 100°C, 3h D130[a]
Diesel fuel (D)	0.8616	1.4814	12.70	27.6	42.9	45.25	52	−18	0.26	1a
Dinçer oil (DO)	0.9256	1.4763	11.43	31.5		39.54				
10% DO+90% D	0.8684	1.4808	12.69	27.2						
20% DO+80% D	0.8746	1.4806	12.52	27.9	42.2	44.06	57	−12	0.20	1a
30% DO+70% D	0.8802	1.4802	12.34	28.3						
40% DO+60% D	0.8870	1.4795	12.21	28.7	40.6	42.91	60			
50% DO+50% D	0.8931	1.4791	12.04	28.8						
60% DO+40% D	0.8979	1.4788	11.92	29.1	38.3					
70% DO+30% D	0.9060	1.4778	11.85	29.4						
80% DO+20% D	0.9124	1.4775	11.76	30.0						
90% DO+10% D	0.9187	1.4768	11.57	30.6						

[a] ASTM test method.

Table 3
Specifications of the Test Engine

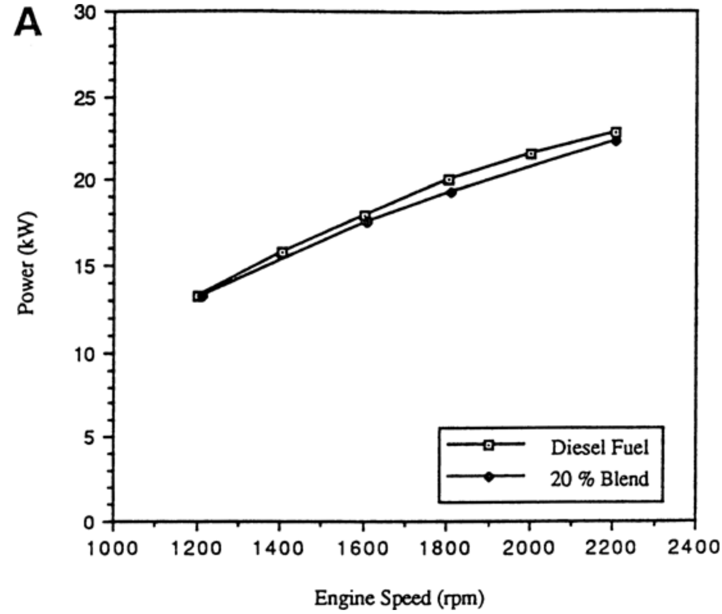
Engine:	Hercules D-2000 NA/DI[a]
Configuration	Inline four cylinder
Piston displacement	3240 cm^3
Combustion chamber	Direct injection
Bore × stroke	9.5 ×11.4 cm
Maximum power	52.2 kW at 2400 rpm
Compression ratio	19:1
Pump type	Single plunger
Injector type	CAV multihole type
Injector timing	12 BTDC

[a]NA = naturally aspirated; DI = direct injection.

Exhaust temperatures were measured with a type K (chromel-alumel) thermocouple. Exhaust gas emissions were continuously measured with Horiba, Model Mexa-534 GE digital exhaust emissions analyzer. Particulates that are the major pollutants in the exhaust gas stream of diesel fuel gave several problems during emission measurements; therefore, a filter system composed of various filtering media was placed on the exhaust outlet to eliminate the particulates (*16,17*). Figures 7, 8 and 9 compare the CO, HC emissions, and exhaust gas temperatures obtained with the blend fuel, and the reference diesel fuel at half- and full-load conditions. Positive decreases in CO and HC emissions were achieved with the 20% blend fuel at half- and full-load conditions compared to diesel fuel. Two separate tests were performed to examine visually and compare the deposit formation on the injector tips using both the 20% blend fuel and reference Grade No. 2-D diesel fuel. The injectors were removed, cleaned thoroughly, and replaced at the beginning of each run. Engine was fueled with each fuel and ran at full load, 2200 rpm, for 1 h. Between each test, the injectors were removed, visually inspected, and tested for any evidence of clogging in the Bacharach model injection testing apparatus. There was no clogging observed with both fuels, and with 20% blend, lower carbonaceous deposits were obtained compared to reference diesel fuel.

CONCLUSIONS

In this study, the possibilities of using safflower seed oil, which is of minor importance for edible and industrial oil markets in Türkiye, as a compression-ignition fuel were investigated. Oil from the Dinçer variety of safflower seed proved to have a convenient fatty acid composition to



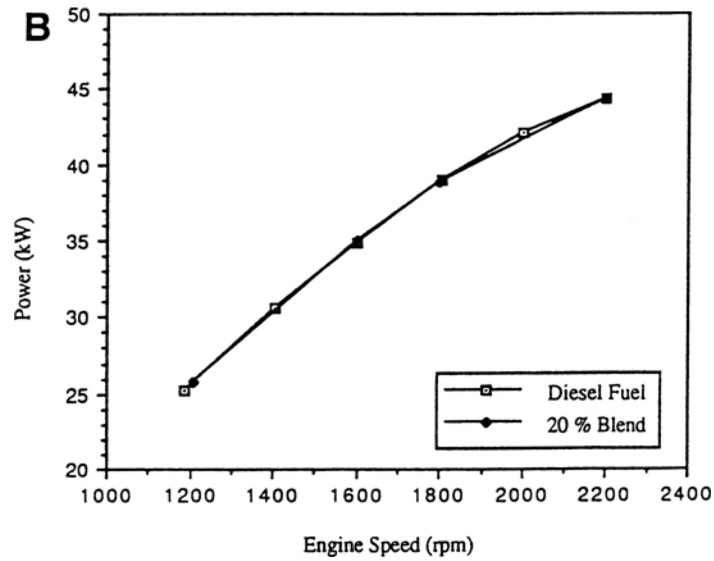


Fig. 2. Power vs speed for Grade No. 2-D diesel fuel and 20% blend fuel. (A) Half load; (B) full load.

be used under the combustion conditions of CI engines. The ASTM standard tests for diesel fuel provided significant insight into the potential of the candidate diesel fuel alternatives and provided suitable screening of prospective fuels. Hence, among the 10–90% Dinçer oil-Grade No. 2-D diesel fuel blends, the 20% blend was selected for the engine tests. The

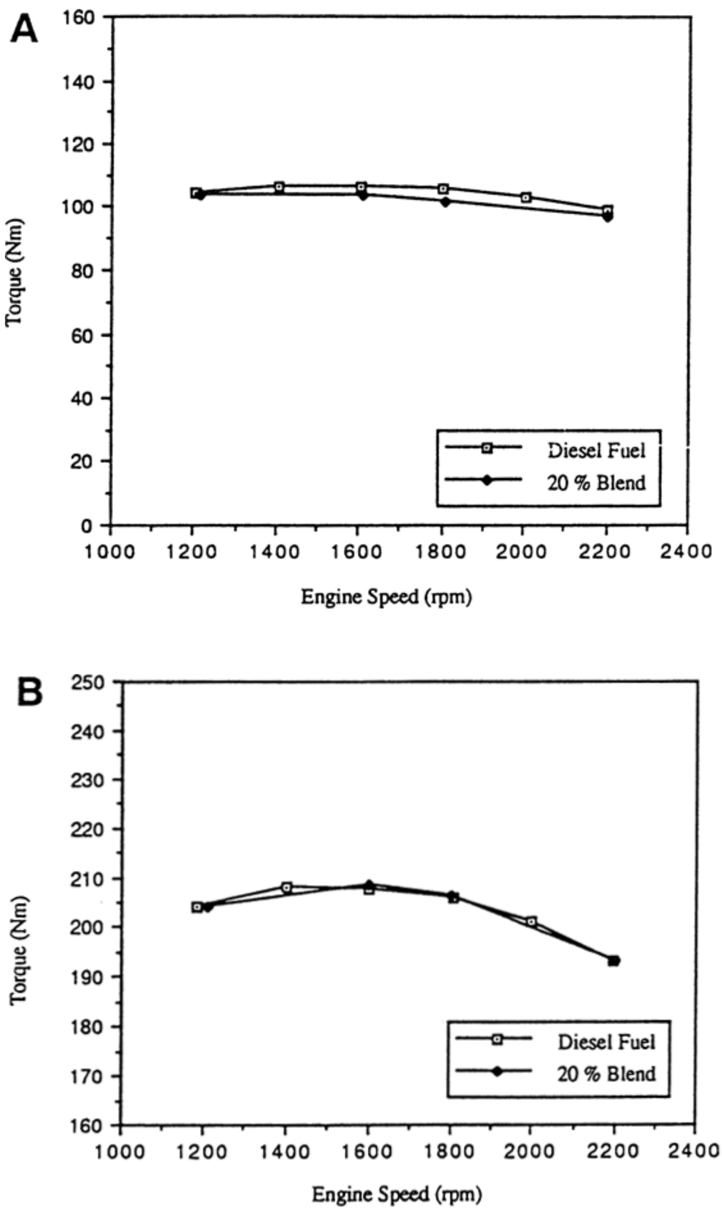


Fig. 3. Torque vs speed for Grade No. 2-D diesel fuel and 20% blend fuel. (A) Half load; (B) full load.

engine performance characteristics obtained with the blend fuel did not differ greatly from that of diesel fuel. A slight power loss, combined with an increase in fuel consumption was experienced with the blend fuel, which was attributed mainly to the lower heating value of the safflower seed oil blended with the diesel fuel. Some positive decreases were

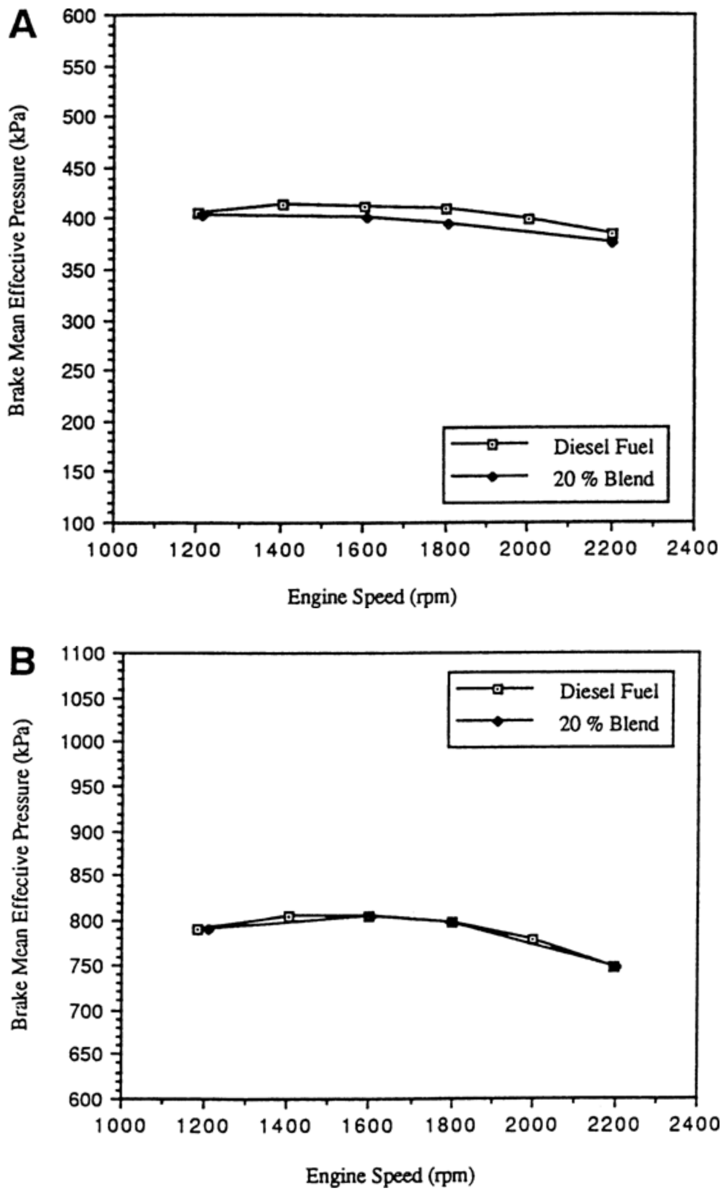
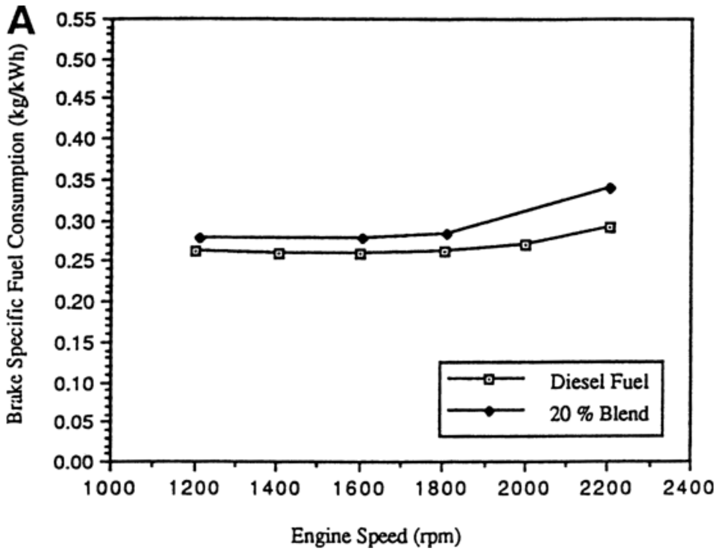


Fig. 4. Brake mean effective pressure vs speed for Grade No. 2-D diesel fuel and 20% blend fuel. (A) Half load; (B) full load.

observed in the carbon monoxide and hydrocarbon emission values with the 20% blend. A total evaluation of the results suggests that the 20% blend fuel can be used as a fuel alternative on a short-term basis. Long-term engine tests need to be performed to support the inspiring results of this study.



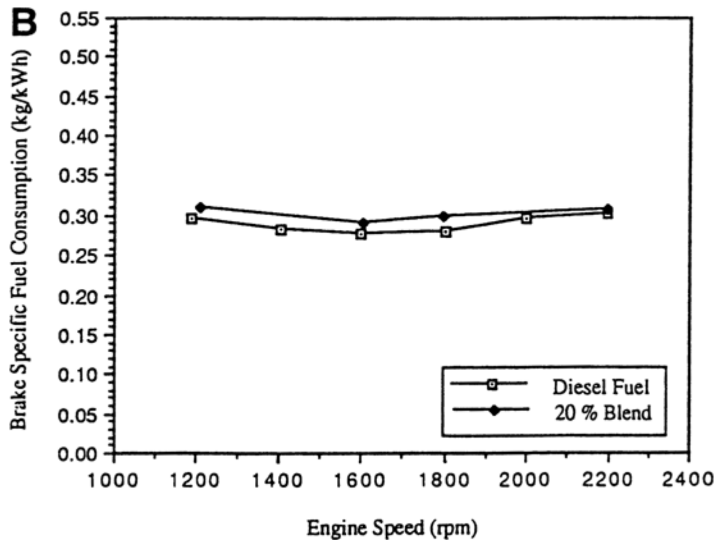


Fig. 5. Brake-specific fuel consumption vs speed for Grade No. 2-D diesel fuel and 20% blend fuel. (A) Half load; (B) full load.

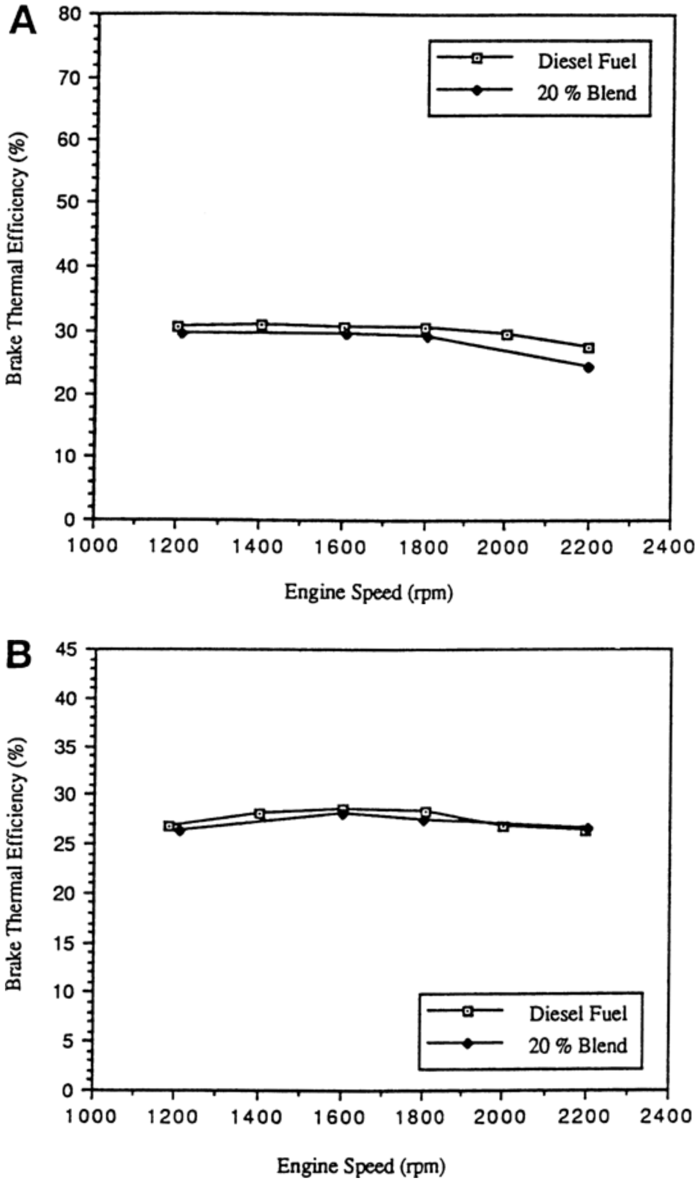


Fig. 6. Brake thermal efficiency vs speed for Grade No. 2-D diesel fuel and 20% blend fuel. (A) Half load; (B) full load.

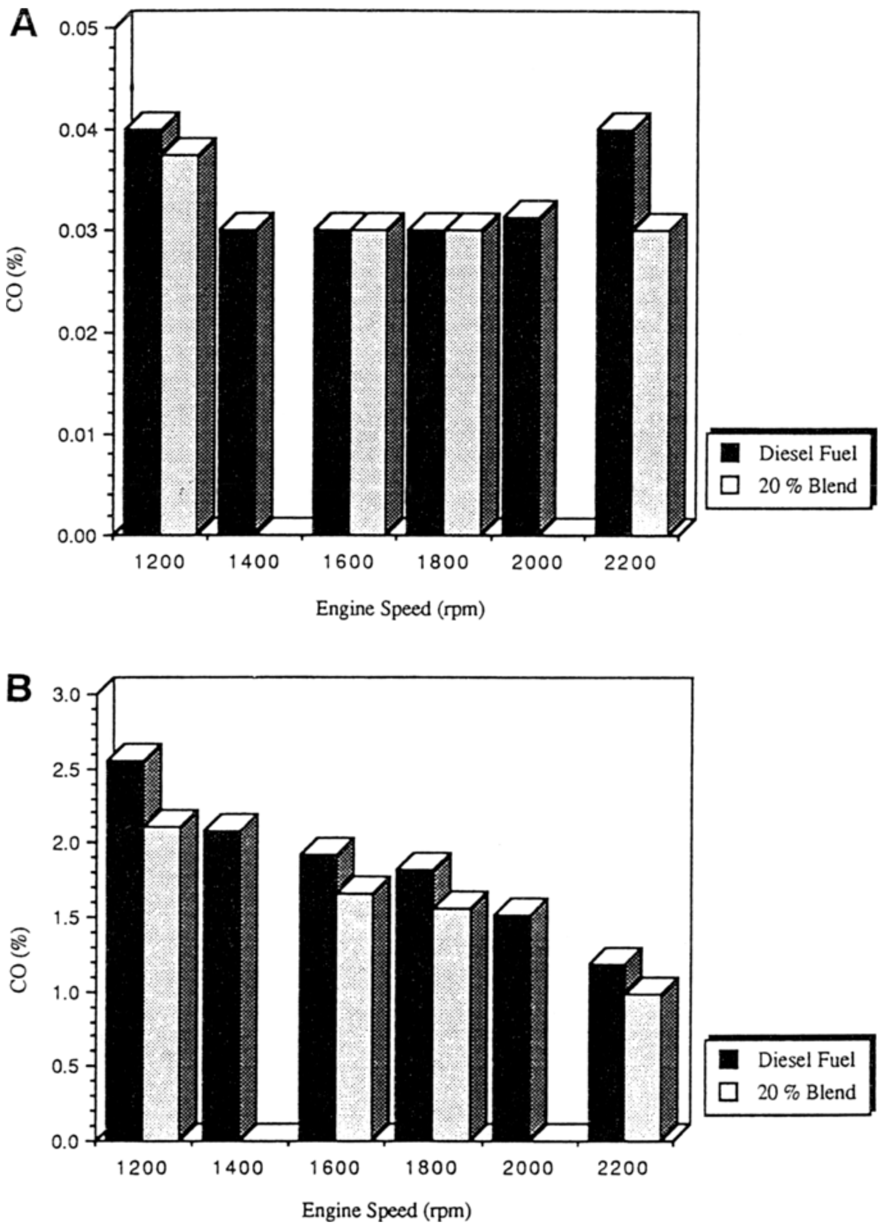


Fig. 7. CO emissions vs speed for Grade No. 2-D diesel fuel and 20% blend fuel. (A) Half load; (B) full load.

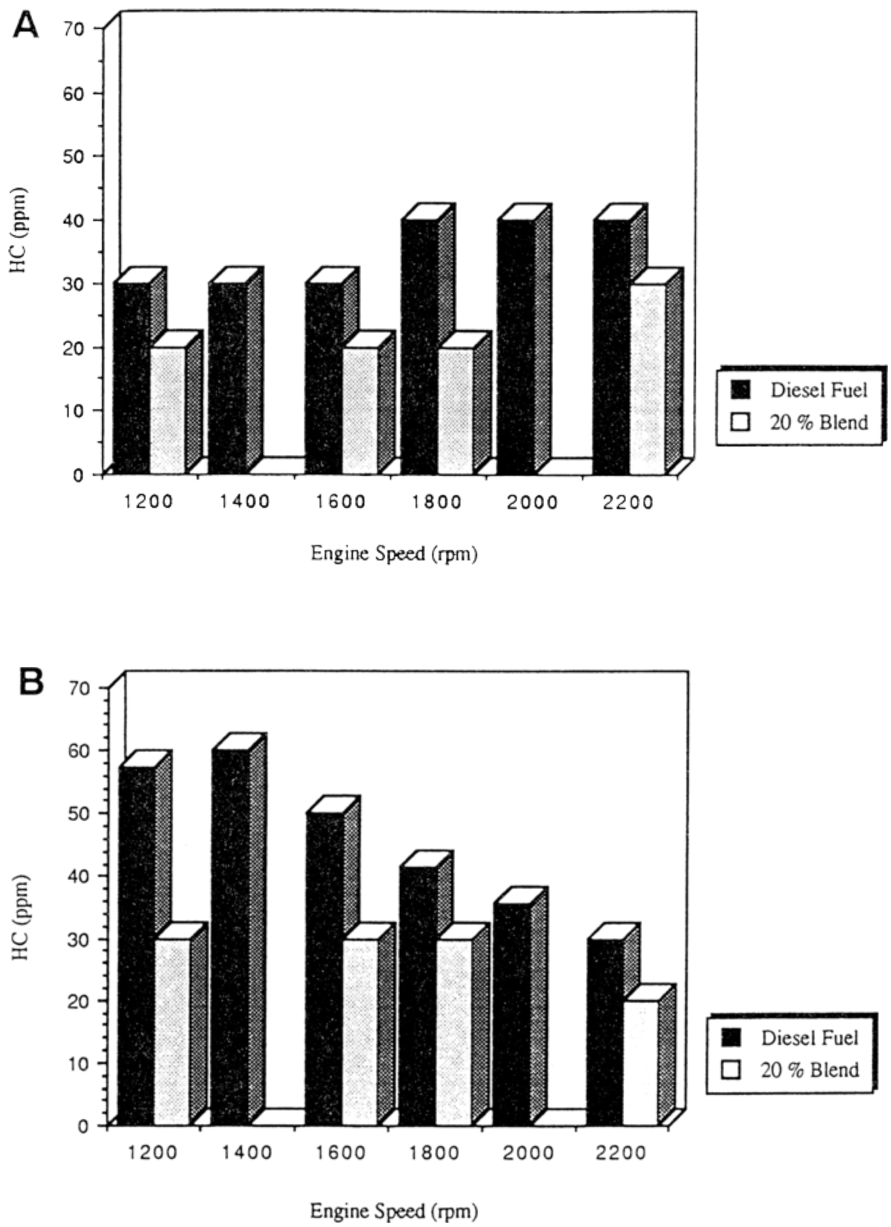
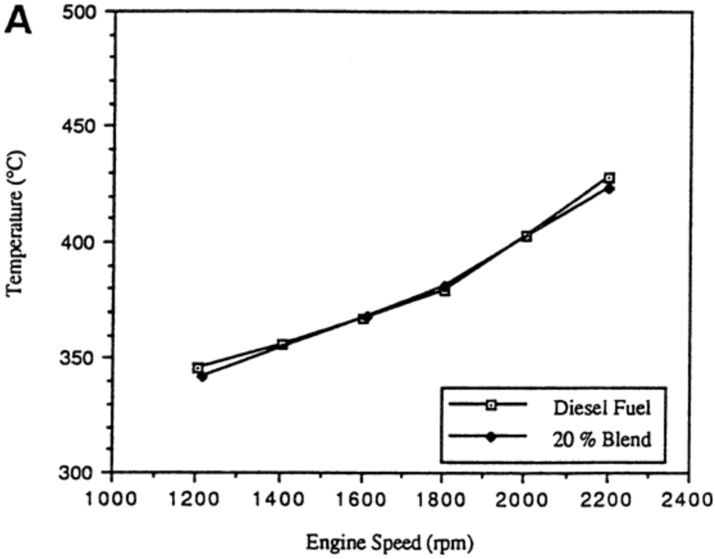


Fig. 8. HC emissions vs speed for Grade No. 2-D diesel fuel and 20% blend fuel. (A) Half load; (B) full load.



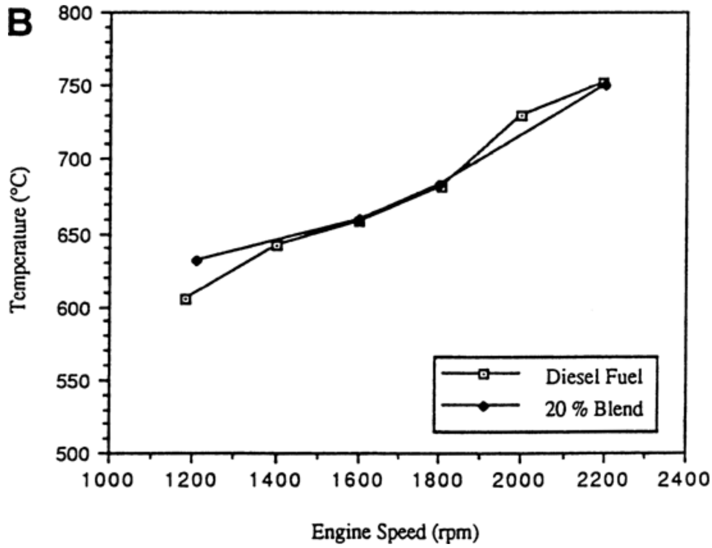


Fig. 9. Exhaust temperature vs speed for Grade No. 2-D diesel fuel and 20% blend fuel. (A) Half load; (B) full load.

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