Turkish J. Eng. Env. Sci.
32 (2008) , 133 – 141.

Use of Hazelnut Kernel Oil Methyl Ester and Its Blends as Alternative Fuels in Diesel Engines

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Received 26.03.2007

Abstract

Interest in vegetable oil as an alternative to diesel fuel in diesel engines has increased during the last few decades because reserves of petroleum fuel and its derivatives are diminishing rapidly, and because they have harmful effects on the environment. In this study, hazelnut (*Corylus avellana* L.) kernel oil was evaluated as an alternative fuel in diesel engines. Firstly, the optimum transesterification reaction conditions for hazelnut kernel oil, with respect to reaction temperature, volumetric ratio of reactants, and catalyst, were investigated. Secondly, an experimental investigation was carried out to examine performance and emissions of a direct injection diesel engine running on hazelnut kernel oil methyl ester and its blends with diesel fuel. Results showed that hazelnut kernel oil methyl ester and its blends with diesel fuel are generally comparable to diesel fuel, according to engine performance and emissions.

Key words: Transesterification; Hazelnut kernel oil methyl ester; Blends; Performance; Emissions

Introduction

It is known that a new energy crisis is expected within decades due to diminishing fossil fuel reserves. Additionally, awareness of the augmented environmental pollutions created as a result of petroleum-fuelled engine emissions is increasing. In developed/developing countries, which do not have sufficient petroleum resources, the cost of importing large quantities petroleum fuel for transport and agriculture, and by commercial, domestic, and industrial sectors for the generation of power/mechanical energy, has rapidly increased. Substituting even a small fraction of total petroleum consumption with alternative fuels will have a significant impact on the economy and environment. Therefore, energy conservation and management, energy efficiency, alternative fuels, and environmental protection have become increasingly important. These conditions have sparked the search for alternative fuels, which should be renewable, readily available, sustainable, environmentally friendly, and techno-economically competitive (Barnwal and Sharma, 2005).

Biodiesel obtained from vegetable oils has been considered a promising option (Puhan et al. 2005). Biodiesel, being renewable, is widely available from a variety of sources, is sustainable as a result of its ability to be used in diesel engines without any modification, has low sulfur content (close to zero), and hence causes less environmental damage than diesel fuel (Ramadhas et al., 2004).

A number of studies have shown that vegetable oils hold promise as alternative fuels for diesel engines; however, several chemical properties of oils, among them high viscosity and high molecular weight, cause poor fuel atomization and low volatility, leading to incomplete combustion and severe engine deposits, injector coking, and piston ring sticking (Dorado et al., 2004). Improving the viscosity of vegetable oil by blending, pyrolysis, and emulsification does not solve the problem completely. Research has shown that one way to improve the fuel properties of oils and fats is the transesterification method (Isigigur et al., 1994; Meher et al., 2006). Transesterification is a process for converting vegetable oil into biodiesel fuel. Chemically, transesterification means taking a triglyceride molecule or a complex fatty acid and neutralizing the free fatty acids, removing the glycerin, and creating an alcohol ester. This process produces a fuel that can be operated in unmodified diesel engines (Demirbas, 2002).

Numerous vegetable oil esters have been tried as alternatives to diesel fuel. Many researchers have reported that with the use of vegetable oil ester as a fuel in diesel engines there is a decrease in harmful exhaust emissions and engine performance that is the equivalent of diesel fuel (Graboski and McCormick, 1998; Yücesu et al., 2001; Almeida et al., 2002; Kalligeros et al., 2003; Pramanik, 2003; Huzayyin et al., 2004; Ramadhas et al., 2005).;Several studies have found that biodiesel emits far less of the most regulated pollutants than standard diesel fuel. Decreasing carbon dioxide (CO_2) emissions by using biodiesel contributes to reducing the greenhouse effect. Furthermore, diminishing carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and smoke density improves air quality (Alfuso et al., 1993; Choi et al., 1997; Baldassarri et al., 2004; Lee et al., 2004; Raheman and Phadatare, 2004;).

Essential oils that have been tested in diesel engines are soybean, sunflower, corn, safflower, cottonseed, and rapeseed, which are categorized as edible oils (Recep et al., 2001); however, some edible oils, such as neat hazelnut kernel oil, have not been comprehensively tested as alternative fuel in diesel engines. Nonetheless, some experimental investigations related to biodiesel produced from a hazelnut soapstock/waste sunflower oil mixture (Usta et al., 2004), and some basic testing with neat hazelnut kernel oil methyl ester (Altıparmak et al., 2004; Gül et al., 2005; have been performed.

As Turkey is the world's main hazelnut producer, hazelnut kernel oil can be used in Turkey as an alternative diesel fuel, especially by farmers of the Black Sea region, which is the main production area. Hence, a study was carried out to run a diesel engine with transesterified hazelnut kernel oil (produced from Turkish hazelnuts) and its blends with diesel fuel at the Automotive Division, Department of Mechanical Education, Marmara University. Suitable transesterification conditions for hazelnut kernel oil methyl ester (HOME) production, in terms of viscosity, density, and ester transformation rate, were investigated and its major physical and chemical properties were determined. A direct injection diesel engine was equipped with instruments for the measurement of performance and emission parameters. The engine tests were carried out with 100% HOME and diesel fuel-HOME blends (containing 5%, 20%, and 50% HOME by volume).

Experiment

Transesterification of hazelnut kernel oil

HOME was produced as an alternative fuel by the transesterification method. The hazelnut kernel oil used in the transesterification process was obtained from a commercial source. The percentage of oil converted to biodiesel using the transesterification process and the physical properties of the biodiesel that was produced changed according to the transesterification process conditions. Fuel for the engine experiment was produced under optimum reaction conditions, which were determined after a series of experiments.

Single-stage laboratory transesterification was performed in a small rectangular container equipped with an electrically operated stirrer. A photo of the transesterification system is shown in Figure 1. Catalysts (NaOH and KOH) dissolved in methanol were added to stirred and heated (60, 65, and 70 °C) oil in order to obtain mixtures with specific volumetric ratios (1:4, 1:5, and 1:6) of oil to methanol. Stirring continued for 1 h at constant temperature; then the mixture was separated in the same container and the glycerol was allowed to separate for a minimum of 3 h. After draining off the glycerol the methyl ester was washed twice with a 1:1 volume of distilled water for 1 h to remove excess methanol and glycerol. Residual water was removed by heating.

Fuel properties

Fuel properties for neat HOME and its blends were determined at the laboratories of TÜBİTAK-MAM (The Scientific and Technological Research Council of Turkey Marmara Research Center). In this report experimental HOME-diesel fuel blends are denoted as BX, indicting a blend including X% HOME (i.e. B5 indicates a blend including 5% HOME) and B100 indicates 100% HOME.

Viscosity and density were determined according to ASTM D88 and ASTM D4052, respectively. The percentage of methyl ester was determined by dividing the volume of methyl ester by the total volume of oil and methanol.

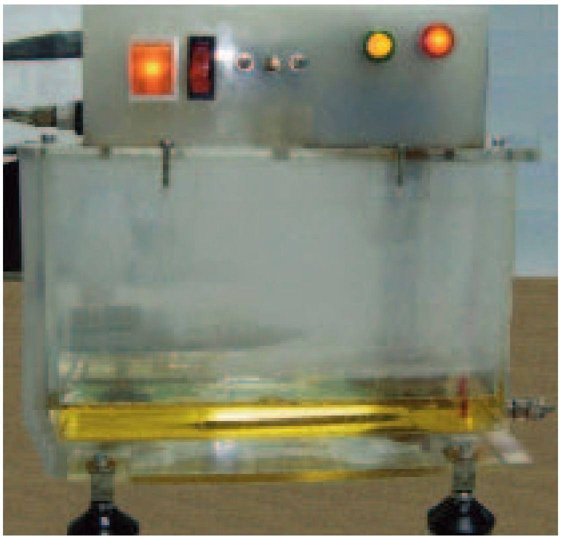

Figure 1. Transesterification system used for the production of HOME.

Experimental equipment for performance and emissions measurements

The performance and emission parameters of prepared neat HOME (B100) and its diesel fuel blends (B5, B20, and B50) were studied and compared to No. 2 diesel fuel. A schematic diagram of the experimental set-up is shown in Figure 2. The diesel engine used for the study was a direct injection, single cylinder, 4-stroke, air-cooled engine. Details of the engine are given in Table 1. The engine was loaded by an electrical dynamometer rated at 10 kW and 380 V. The load on the dynamometer was measured using a strain gauge load sensor. An inductive pickup speed sensor was used to measure the speed of the engine. Fuel consumption was measured with a burette (10 and 20 ml volumes) and a stopwatch. Exhaust gas, lubricating oil, and air-fuel inlet temperatures were measured with K-type thermocouples. The engine was started on neat diesel fuel and warmed up. The warm up period was assumed to end when the engine reached a stabilized working condition (i.e. when the engine lubricating oil temperature reached 65 ± 5 °C). Parameters, including speed of operation, fuel consumption, and load, were measured. Brake power, brake specific fuel consumption, brake specific energy consumption, and brake thermal efficiency were computed. Emissions, including carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen oxide (NOx) were measured using an exhaust gas analyzer, and smoke density was measured using a smoke analyzer. All measurements were recorded in triplicate to obtain average values. Engine performance and emissions characteristics are presented according to engine load. A photo of the experimental apparatus is shown in Figure 3.

Table 1. Main characteristics of the test engine.

Trademark and model	Lombardini 6 LD 400
Number of cylinders	One
Bore	86 mm
Stroke	68 mm
Swept volume	395 cm^3
Compression ratio	18:1
Maximum engine speed	3600 rpm
Maximum engine power	8 kW
Maximum engine moment	21 Nm at 2200 rpm
Injector opening pressure	200 Bar
Number of nozzle hole	4
Fuel injection timing	20 BTDC

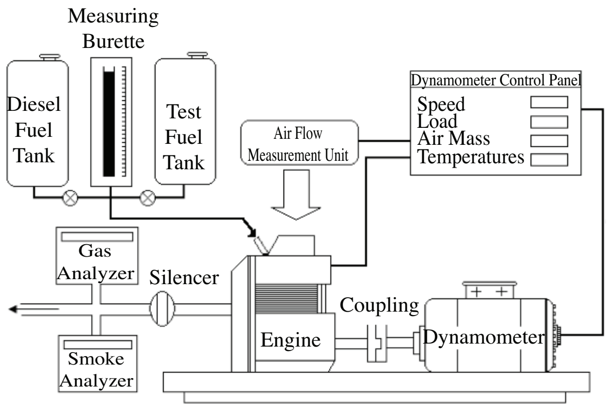

Figure 2. Schematic diagram of the experimental set-up.

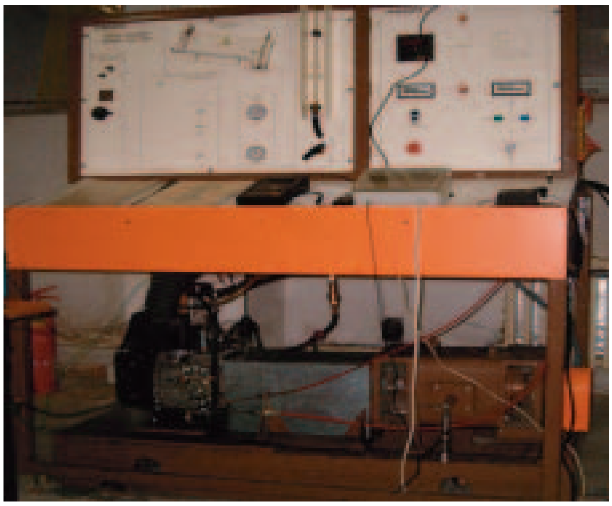

Figure 3. The experimental apparatus used for testing.

The accuracy of the measurements and the results of uncertainty analysis of the calculated results are shown in Table 2. Engine performance and exhaust emissions were studied at different engine loads and constant engine speed. Maximum torque was achieved at 2200 rpm.

Table 2. The accuracy of the measurements and the uncertainties in the calculated results.

Measurements	Accuracy
Load	± 2 N
Speed	± 2 rpm
Time	± 0.5%
Temperatures	± 1 ^{o}C
CO	± 0.001%
CO_2	± 0.01%
NOx	± 1 ppm
Opacity	± 0.1%
Calculated results	Uncertainty
Power	± 2.55% max
BSFC	± 2.60% max
BTE	± 2.60% max

Results and Discussion

HOME Production and its characterization

Variations in transesterification yield, viscosity, and density, with respect to reaction temperature, volumetric ratio of oil to methanol, and type of catalyst, are shown in Figures 4, 5, and 6, respectively. In the transesterification reaction higher methyl ester yield, higher density, and lower viscosity are desired; Therefore, as seen in the figures the optimum transesterification reaction conditions were reaction temperature 65 °C; volumetric ratio of reactants 1:5; catalyst KOH. The HOME used in the experiments was produced under these conditions.

Biodiesel properties are very important and should be considered before testing in an engine. The kinematic viscosity of the HOME and No. 2 diesel fuel used in the experiments were measured at 40 °C. Transesterification of hazelnut kernel oil provided a significant reduction in viscosity. The variation in HOME viscosity was very close to that of the diesel fuel and was reduced further by increasing the amount of diesel in the blend. A similar reduction in specific gravity was also observed; however, the calorific value of HOME was 37.23 MJ/kg, which is less than the calorific value of diesel (43.15 MJ/kg). As the percentage of diesel in the blends increased, the calorific value increased. The flash point of

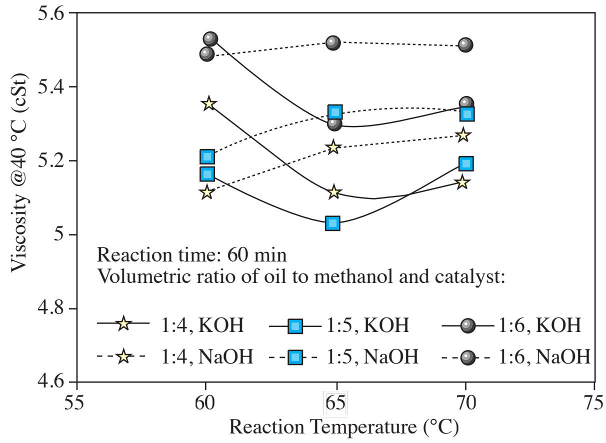

Figure 4. Variation in viscosity.

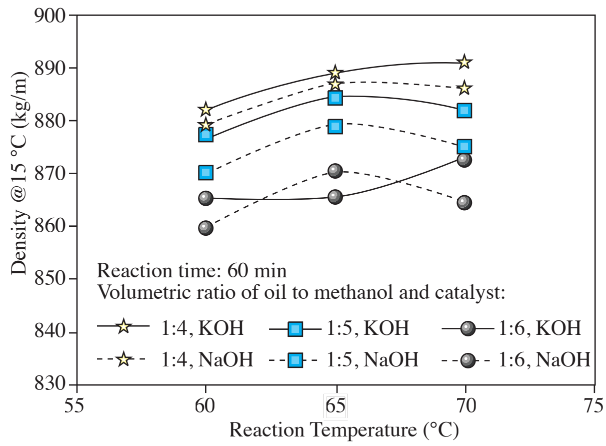

Figure 5. Variation in density.

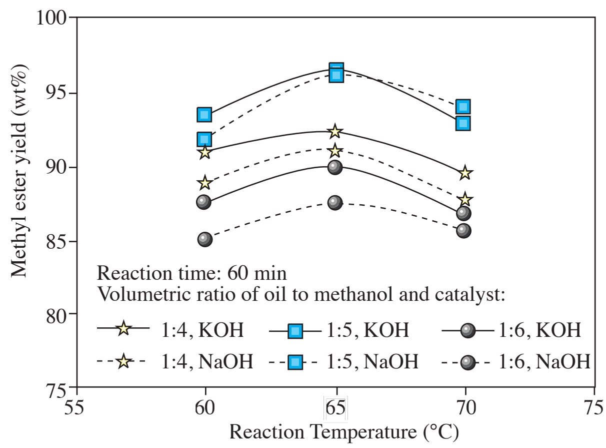

Figure 6. Variation in methyl ester yield.

Table 3. Properties of diesel fuel and HOME.

Property	Method	EN 14214	Diesel	B100	B50	B20	B5
Density (kg/m^3 15 °C)	ASTM D 4052	860 - 900	830	884.3	857.1	840.8	832.7
Viscosity (cSt 40 °C)	ASTM D 88	3.5 - 5.0	2.4	5.4	3.9	3.0	2.6
Calorific value (MJ/kg)	ASTM D 240	——	43.15	37.23	40.2	41.9	42.9
Cetane number[a]	——	51.0 min	50	55	52.5	51	50.3
Flash point (°C)	ASTM D 93	101 min	59	182.5	120.8	83.7	65.2
CFPP (°C)	EN 116	——	-10	-14	-12	-10.8	-10.2
Ash (mass %)	ASTM D 482	——	0.001	0.008	0.0045	0.0024	0.0013
Water (volume %)	ASTM D 6304	——	0.0002	0.0028	0.0015	0.0007	0.0003

[a]Calculated from the cetane index (distillation temperature, ASTM D 976).

HOME was determined to be $\geq$ 100 °C, indicating that is can be safely stored and handled. The properties of No. 2 diesel fuel and HOME are given in Table 3.

Engine performance

Brake thermal efficiency Variations in brake thermal efficiency (BTE), with respect to load, for all of the fuels are shown in Figure 7. BTE of all the tested fuels initially increased with engine load until it reached a maximum value and then decreased slightly as engine load continued to increase. According to the HOME content of the blends, BTE initially increased and reached a maximum value with the B20 blend and then decreased as the HOME content in the blends increased. The minimum BTE was obtained with B100.

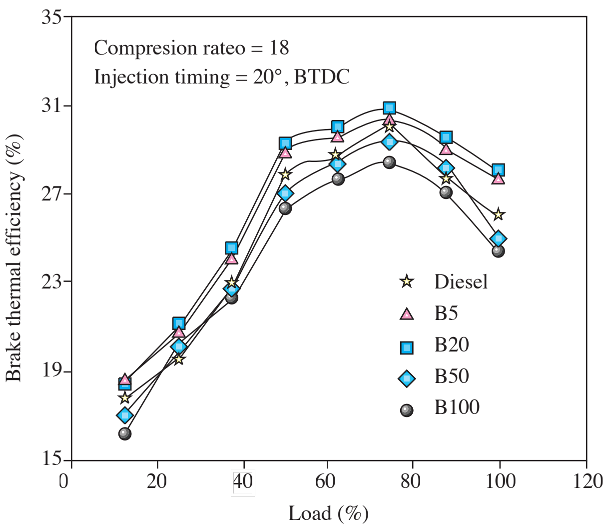

Figure 7. Variation in brake thermal efficiency.

Maximum brake thermal efficiency was 30.35% and 30.80% for B5 and B20, respectively, which was higher than that of diesel (29.96%). Maximum brake thermal efficiency was 29.39% and 28.36% for B50 and B100, respectively, which was lower than that of diesel fuel due to HOME's higher viscosity.

Although the addition of the HOME to diesel fuel decreased its heating value, higher BTE was obtained with B5 and B20. HOME includes approximately 10% (in weight) oxygen that can be used in combustion, especially in the fuel-rich zone. This is one possible reason for its more complete combustion and higher BTE; however, as HOME content in the blends increased (B50 and B100) BTE decreased due to lower heating value and higher viscosity, which result in slightly poorer atomization and combustion. By increasing the HOME content in fuel blends the negative effects of HOME's lower heating value and higher viscosity outweigh the positive effect of HOME's oxygen content (Ramadhas et al., 2004; Usta et al., 2004).

Brake Specific fuel consumption Variations in brake specific fuel consumption (BSFC), with respect to engine load, of diesel fuel, HOME, and the experimental blends are presented in Figure 8. For all of the fuels tested, BSFC had a tendency to decrease as engine load increased until it reached a minimum value, and then slightly increased as engine load continued to increase.

BSFC initially decreased slightly as HOME content in the blends increased up to 20%, but increased as HOME content increased further due to HOME's lower calorific value and higher viscosity. In blends B5 and B20, BSFC was 0.61%-5.5%, lower than that of diesel, whereas in blends B50 and B100, BSFC was 5.63%-12.66%, higher than that of diesel.

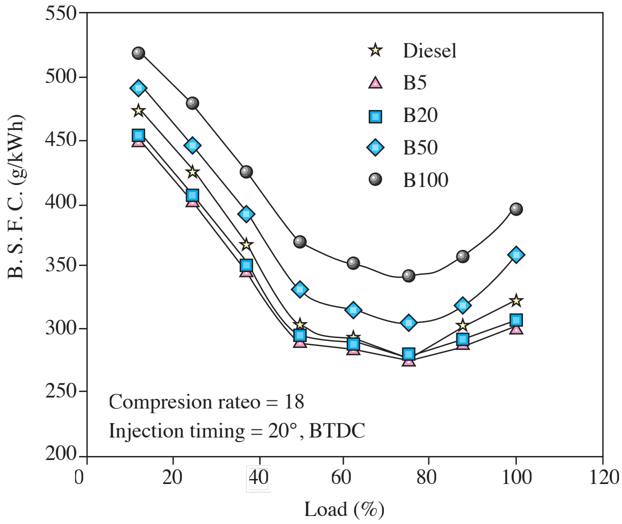

Figure 8. Variation in brake specific fuel consumption.

Exhaust gas kemperature Exhaust gas temperature (EGT) varied with load and the results for different fuels are presented in Figure 9. EGT of all the tested fuels increased with load. EGT of B5 and B20 was higher than that of diesel fuel at the highest load due to the blends' higher viscosities, which resulted in poorer atomization, poorer evaporation, and extended combustion during the exhaust stroke. When HOME content increased (B50, B100) viscosity increased, and, as a result, EGT of the blends was lower than that of diesel fuel due to a deterioration in combustion and more fuel being oxidized. This was confirmed by BTE and BSFC measurements. Maximum EGT at peak load was 526 °C for B100 and 531 °C for diesel, while the maximum EGT of B5 was 542 °C.

Engine exhaust emission

Carbon Dioxide Emissions Figure 10 compares the carbon dioxide (CO_2) emissions, with respect to engine load, of various fuels tested. CO_2 emissions of all the fuels had a tendency to increase with load. CO_2 emissions initially increased with HOME content in the blends, reaching a maximum value with the B20 blend and then decreased as HOME content continued to increase. B100 fuel had the lowest level of CO_2 emissions.

Higher amounts of CO_2 in exhaust emissions are an indication of complete fuel combustion. As such, higher CO_2 emissions of B20 indicated effective combustion due to the oxygen content of HOME, which improves fuel combustion. This was confirmed by variations in BTE and BSFC. Fuel blends with higher HOME content emitted lower amounts of CO_2 emissions as a consequence of HOME's higher viscosity. The fuel spray cone angle, which depends on air entrainment, decreases with increased fuel viscosity. Decreasing the cone angle results in a reduction in the amount of air entrainment in the spray. Lack of sufficient air in the fuel spray impedes the completion of combustion and reduces CO_2 emissions (Nwafor, 2004).

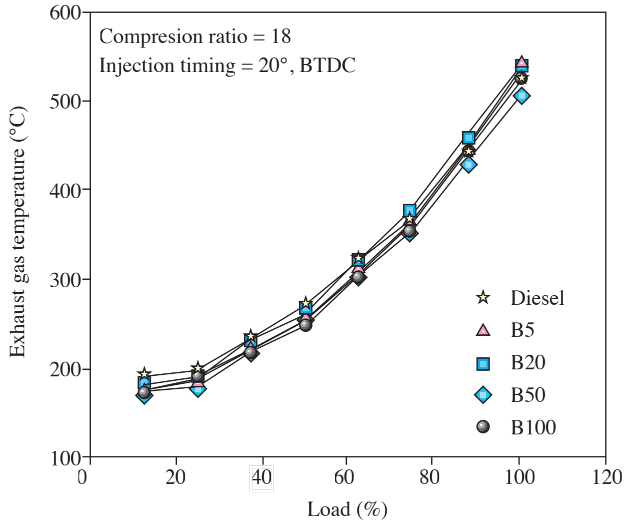

Figure 9. Variation in exhaust gas temperature.

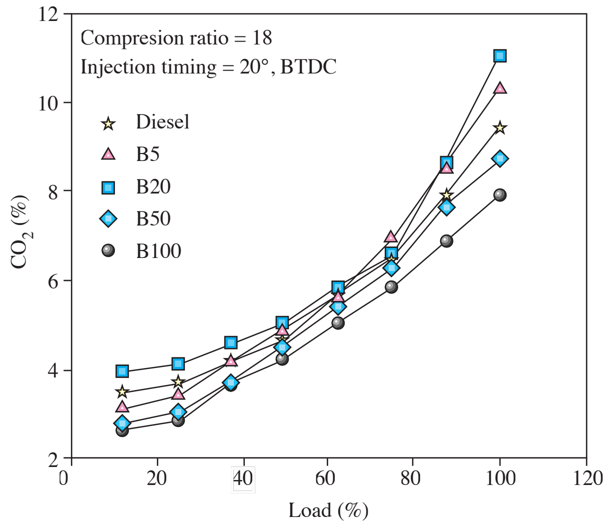

Figure 10. Variation in CO_2.

Carbon monoxide emission Figure 11 shows the plots for carbon monoxide (CO) emissions of the tested fuels operated at the rated engine speed of 2200 rpm at various load conditions. CO emissions increased with load because the air-fuel ratio decreased as the load increased, which is typical of internal combustion engines.

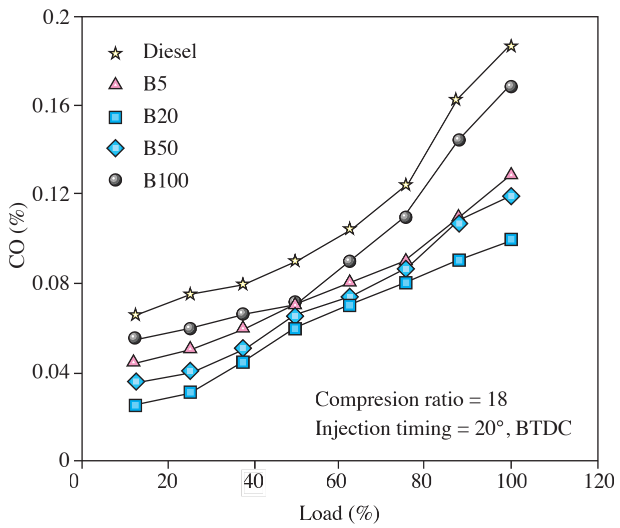

Figure 11. Variation in CO.

CO emissions initially decreased as HOME content in the blends increased, reaching a minimum with the B50 blend, because the oxygen content in HOME facilitates complete combustion (Kumar et al., 2003); then, CO emissions increased as HOME content increased (B100) due to HOME's higher viscosity, which results in poorer atomization and combustion.

Nitrogen oxides emission Figure 12 shows the variation in nitrogen oxides (NOx) with brake power. NOx emissions for HOME and its blends were lower than for diesel fuel. NOx emissions decreased as HOME content in the blends increased, reaching a minimum value with B100 due to lower mean temperature in the cylinder.

NOx were reported by several researchers to increase with biodiesel (Rickeard and Thompson, 1993; Usta, 2001; Çanakci, 2005), whereas Dorado et al. (2004) reported lower NOx emissions. NOx emissions are determined by oxygen concentration, peak pressure, combustion temperature, and time. The heating value of HOME is less than that of diesel fuel. In addition, as the cetane number for HOME is high, the ignition delay may be reduced, which in turn may reduce the peak pressure rise that occurs during the initial portion of the combustion process (Scholl, and Sorenson, 1993); hence, mean temperature in the cylinder is reduced, and this low pressure and low temperature in the second stage of combustion process may reduce NOx emissions.

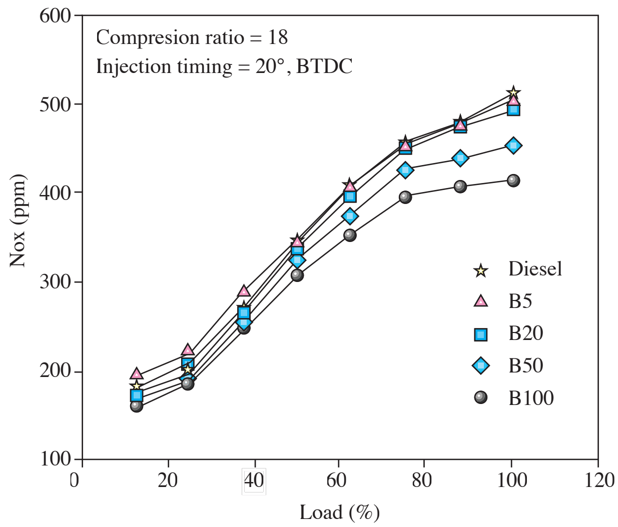

Figure 12. Variation in NOx.

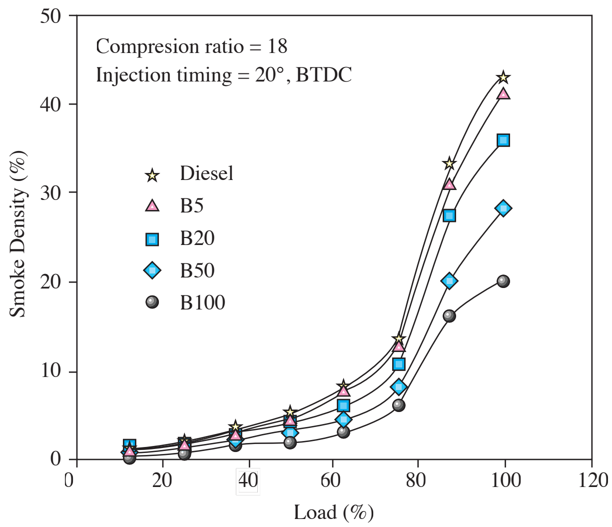

Figure 13. Variation in smoke density.

Smoke density Figure 13 depicts the variation in smoke density with respect to the different fuels tested. As shown in the figure, smoke density decreased as HOME content in the blends increased, reaching a minimum value with B100. In diesel engines smoke formation generally occurs in the fuel-rich zone at high temperature, particularly within the core region of the fuel spray (Puhan et al., 2005).

Because HOME contains oxygen, which decreases regional richness, the formation of smoke is reduced.

Conclusion

In this study, hazelnut kernel oil was tested as an alternative fuel for use in diesel engines. Optimum transesterification reaction conditions of hazelnut kernel oil, with respect to reaction temperature, volumetric ratio of the reactants, and catalyst, were investigated. The test fuel (HOME) used in the experiments was produced under the optimum transesterification reaction conditions. Important properties of HOME and its blends with diesel fuel were similar to those of diesel fuel. HOME and its diesel fuel blends were experimentally studied in a direct injection single cylinder engine, in terms of performance and emissions characteristics. Based on the experimental study the following conclusions are drawn:

- The optimum transesterification reaction conditions for hazelnut kernel oil were reaction temperature 65 °C; volumetric ratio of the reactants 1:5; catalyst KOH.
- Lower HOME content blends (B5, B20) improved BTE of the diesel engine and slightly reduced BSFC. The maximum BTE increased from 29.96% with diesel to 30.80% with B20. Furthermore, B5 and B20 improved exhaust emissions.
- The highest HOME content blend (B50) and neat HOME (B100) resulted in significant improvements in emissions, but they did have better performance characteristics than diesel fuel. Nonetheless, small modifications may provide significant improvements in the performance of B50 and B100.

Consequently, biodiesel produced from hazelnut kernel oil can be used as an alternative fuel in existing diesel engines. Using biodiesel produced from hazelnut kernel oil can improve the agricultural economy and benefit the environment; however, a cost analysis of HOME production compared to the price of conventional diesel fuel should be undertaken due to a recent increase in the price of hazelnut kernel oil.

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