PERFORMANCE AND EMISSIONS ANALYSIS OF A DIESEL ENGINE FUELLED WITH ESTERS PRODUCED FROM PALM OLEIN/SOYBEAN OIL MIXTURE

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Abstract

In this experimental study, the engine performance and exhaust emissions of a diesel direct injection engine using mixed palm olein-soybean vegetable oil ethyl ester (POSEE) and methyl ester (POSME) were studied. The results of experimental studies have shown that the torque and the brake power output of the engine using biodiesels has a little lower value and the specific fuel consumption is higher compared to the engine using conventional disesel. It was also observed a decrease both at CO and HC emissions that indicated an advantage about exhaust emissions. Although methyl esterôs CO_2 emission has decreased compared to the diesel fuel, NO and NOX emissions were higher with the biodiesels.

Keyword: *Biodiesel, Exhaust emissions,Engine Performance, Diesel Engine.*

2. Introduction

The energy need of growing population on the world has been increasing speedly. However, fossil fuels, which are the most important energy source of todayôs world has been decreasing rapidly day by day while polluting the environment. Because of these problems, scientists have been studying on renewable alternative energy sources for a long time. The idea of using vegetable oils as alternative fuel for diesel engines belongs to Rudolph Diesel, who is the inventor of diesel engines [1]. However, several chemical properties of oils and fats are not appropriate for the engine.

The researches have shown that one way to improve the fuel properties of oils and fats is their ótransesterificationö. Transesterification is a chemical reaction which converts a fatty acid to an acid ester. This process provides a fuel, called biodiesel, which can be utilized in unmodified diesel engines [2]. There are several studies about biodiesel on the world. Even though the bigger portion of these studies contains methyl ester, there are also studies about ethyl and other esters. Antolin et al. [3], tested engine performance and emission using four different fuel samples: diesel fuel; 30% sunflower methyl ester, 70% diesel fuel (by volume); 5% sunflower methyl ester, 95% diesel fuel; and 100% sunflower methyl ester. Dorado et al. [2], studied the exhaust emissions of a diesel direct injection Perkins engine fueled with waste olive oil methyl ester at several steady-state operating conditions**.** Kalligeros et al. [4], reported on biodiesel/marine diesel blends as a fuel in an indirect injection single cylinder diesel engine. They have used methyl esters produced from sunflower oil and olive oil as biodiesel..

Al-Widyan et al. [5], tested several ester/diesel blends including 100% ester in addition to diesel fuel, which served as the baseline fuel. Puhan et al. [6], prepared Mahua Oil Ethyl Ester by transesterification using sulfuric acid (H_2SO_4) as catalyst and tested in a 4-stroke direct injection diesel engine with natural aspirated. The objective of another study was to investigate the engine performance and the road performance of biodiesel fuel originated from the used cooking oil in a Renault Megane Diesel engine in winter conditions for 7500 km road tests in urban and long distance traffic[7]. In another study, the effects of methyl ester biodiesel which was produced from a hazelnut soapstock/waste sunflower oil mixture was studied on the performance and emissions of a four cycle, four cylinder, turbocharged indirect injection (IDI) at both full and partial loads [8].

Usta [9], performed an experimental study on the performance and exhaust emissions of a turbocharged indirect injection diesel engine fuelled with tobacco seed oil methyl ester at full and partial loads. Raheman et al. [10], presented the results of a study investigating the fuel properties of karanja methyl ester (KME) and its blend with diesel from 20% to 80% by volume and running a diesel engine with these fuels. Kalam et al. [11], presented the experimental results carried out to evaluate the effect of anticorrosion additive in biodiesel (from palmoil) on diesel engineôs performance, emissions and wear characteristics. Ramadhas et al. [12], used various blends of biodiesel (from rubber seed oil) and diesel as fuel in compression ignition engines and analyzed its performance and emission characteristics. WinLee et al.ôs study [13] covered short-term laboratory investigations of a 20% (by volume) soybean methyl ester blend.

In comparison to diesel, the higher cetane number of biodiesel results in shorter ignition delay and longer combustion duration and hence results low particulate emissions and minimum carbon deposits on injector nozzles[14]. In general, it has been reported by most researchers that using biodiesels donôt require important modifications on engine. CO, HC and particulate emissions decrease, NO_X emissions sometimes increase, sometimes decrease. Because of their chemical structure, SO_X emissions donôt occur [15].

In this sense, the aim of this work is to carry out performance and emission test of a single cylinder, 4-stroke, diesel direct injection engine fueled with biodiesels (palm olein-soybean ethyl ester-POSEE and palm olein-soybean methyl ester-POSME) from mixed, refined edible palm olein-soybean oil and petroleum based diesel. The emission data includes carbon monoxide (CO), hydrocarbons (HC) and oxides of nitrogen (NO and NO_X)

3. Biodiesel production and specifications

In the experiments, petroleum based diesel and mixed vegetable oil methyl and ethyl esters were used as fuels. The raw material óoilô was supplied ready-made to produce the esters. This oil had been produced mixing 35% refined palm olein oil and 65% refined soybean oil by an óoil productor firmô in Turkey.

In order to produce methyl ester, 1-liter oil, 200-ml. methanols and 3,5 gr KOH (as a catalyst) were used. Ethyl ester process is similar to the methyl ester process with a difference in the amount of reaction elements, which are more than the ones in methyl ester process. In order to produce it, 1- liter oil, 300 ml. ethanol and 10 gr. KOH were used[16,17].

Both biodieselsô physical and chemical properties, which have been analyzed in Middle East Technical University Petroleum Research Centre in Turkey and diesel fuelôs properties, are summarized in Table 1.

4. Experimental equipments and test procedure

The experimental setup consists of a Diesel engine, an engine test bed and a gas analyser. The schematic layout of the test system can be seen in Fig 1. A single cylinder, four stroke, direct injected diesel engine was selected for the tests. The technical specifications of the test engine are summarized in Table 2. The diesel engine has air-cooling system. The engine test bed (Cussons-P8160) consists of a control panel, measurement instruments and an electrical dynamometer that is rated for 24,1 Nm power absorption at 4750-rpm maximum operating speed. Cussons P8160 type electrical dynamometer is a direct current machine that turns with the diesel motor. The force, which is produced by the motor, can be measured with using load cells that is 0,25 m far away from the centre of the dynamometer. The control panel of the dynamometer carried out setting the experiment conditions and reading the measurement results. On the control panel, thereôs a button to set the motor load, a digital screen to read the motor load and the rotation value. The fuel consumption was measured with a burette (10 ml volume) and a stopwatch. And also, an oblique manometer was used to measure air consumption. The lubricating oil, fuel and ambient temperatures were measured by thermocouples and read from the digital screen of control panel.

The exhaust gas was given to atmosphere by a gas ventilation system. The exhaust gas emission measurements were measured with a Quintox Kane-May emission gas analyzer. The device was placed approximately 1 m away from the engine. The gas analyser, having electrochemical sensors, was used to measure the CO, CO_2, NO, NO_X, O_2 and HC emissions. This apparatus can also measure the exhaust gas temperature.

The parameters were obtained during full load and variable speed performance tests. The engine was operated on diesel fuel at first and then on POSME and POSEE fuels. After a standard warm-up procedure, the engine speed was increased to 3000 rpm The tests and data collection were performed at seven different engine speeds; 3000, 2700, 2400, 2100, 1800, 1500 and 1200 rpm. At each speed, the engine was stabilised and then the measurement parameters were recorded.

5. Results and discussion

Engine performance

Fig. 2 shows the engine torque values according to the engine speed variations. The maximum torque with diesel fuel operation was 20,15 Nm at 1800 rpm. POSEEôs maximum torque was 18,5 Nm at 2100 rpm and POSMEôs maximum torque was 18,775 Nm at 1500 rpm. The average torque decrease for POSME was 12,5% and for POSEE was 12,36%.

The variations of engine power values in relation with the engine speeds are shown in Fig. 3. The maximum power with diesel fuel operation was 4,93 kW at 2400 rpm. Observed maximum power values of biodiesel fuel operations were also around 2400 rpm but less than the diesel fuel value for each fuel. The average power differences between the diesel fuel and POSME and POSEE were about 16% and 16,9%, respectively.

The specific fuel consumption is one of the important performance parameters of an engine and is defined as the consumption per unit of power in a unit of time. Test results showed that the obtained minimum specific fuel consumption values were in the vicinity of the maximum torque area. As shown in Fig. 4, the minimum specific fuel consumption values were 309,75 gr/kWh with diesel fuel, 322,4 gr/kWh with POSME and 332,4 gr/kWh with POSEE.

The performance values of biodiesels have disadvantages when compared with diesel fuel. These results may be due to the higher viscosity and lower heating values of biodiesels. Because of the higher viscosity, the spraying quality decreases in injectors. So this factor extends the time of fuel evaporating and burning. The fuel burning occurs at expansion time of cylinder and performance decreases [1,15]. The higher exhaust temperatures of biodiesels can indicate that the fuelôs energy isnôt used at work time of motor exactly and exits with the exhaust gas.

From the performance viewpoint of biodiesels, POSME has advantages at lower engine speeds and POSEE has advantages at higher engine speeds. POSEEôs lower heating value is a little higher than POSMEôs lower heating value. At that time, the advantage of POSME at lower engine speeds may be attributed to the higher fuel mass flow of the denser and more viscous structure of it. The denser structure of POSME can result in larger mass flow for the same fuel volume, and more viscous fuel means less internal leakage in the fuel pump.

The trends depicted in Fig. 5 for the thermal efficiency indicate that the combustion process proceeded more efficiently with the biodiesels compared to diesel fuel. It can be established that biodiesels possess higher cetane number but we donôt know our experiment fuelôs cetane number. It is seen here that the effect of higher thermal efficiencies of biodiesels were more than offset by the operation at lower fuel air ratios than the diesel fuel.

Exhaust emission

In this section, the emissions of carbonmonoxide, unburned hydrocarbons, carbondioxide, and oxygen, in addition to nitrogen oxide are examined and the results are shown in Figs.6-10 for all the test fuels.

Using of biodiesel fuels resulted in the reduction of unburned HCs and carbonmonoxide (CO) emissions. Fig. 6 illustrates that with average calculation, methyl ester 62%, ethyl ester 43,9% reduced the CO emissions emitted in all cases. Fig.7 exhibit reductions in HC emissions, due to the using POSME and POSEE.

Because of the lower fuel-air equivalence ratios of the biodiesels, poor mixture occurs in the engine and this situation may result with lower HC and CO emissions. Furthermore, since the lower cetane number of the diesel fuel may result in lower tendency to form ignitable mixture, it causes carbonmonoxide and unburned hydrocarbons, which are the products of incomplete combustion [5].

The NO and NO_X emissions were increased in all cases when the two biodiesels were used, as shown in Fig. 8 and Fig. 9. These emissions are usually a result of higher combustion temperatures. At the same time, the oxygen concentration is important at these high temperatures. When we look at the fuel-air equivalence ratios, we see the poor mixtures of biodiesels. And also, the chemical structure of esters may increase the oxygen concentration, which is the reactant of nitrogen oxides reaction. The higher NO_X emissions can be a result of higher exhaust gas temperatures. To reduce NO_X emissons, the injection timing can be retarded by 2-3 degrees. Also, according to a study 18 reducing the iodine value of biodiesel through enriching the parent oil in fatty acids with lower iodine value and addition of cetane improvers can eliminate the NO_X effect.

Fig. 10 illustrate the CO_2 emissions in relation with the engine speeds, respectively. Although POSMEôs CO_2 emissions are generally lower than the diesel fuel, POSEEôs are higher. To explain the reasons of CO_2 emissions, we must know detailed chemical structures of esters and burning reactions.

A study about the exhaust emissions of biodiesels indicates reduction of CO and HC emissions and increase in NO_X emissions in [19], too.

6. Conclusions

Compared to diesel fuel, a little amount of power loss and higher specific fuel consumption occured at biodiesel fuel operations. However, thermal efficiencies of biodiesels were higher. HC and CO emissions of biodiesels were lower than that of diesel fuel, but on the other hand, NO_X and NO emissions were higher. And also, methyl esterôs CO_2 emissions were less.

When we compared POSME and POSEE; performance values are generally same, but the thermal efficiency of POSME is higher. POSME has advantages about CO, HC, CO_2 emissions, too. The price of the methyl alcohol and the succession on transesterification reaction are the other advantages of methyl ester. Because of all these factors, methyl ester is produced and used more than ethyl ester all over the world. But if a countryôs agriculture is highly developed, ethyl ester can become important. When we look at fuel properties, the lower viscosity and cloud point are the advantages of POSEE according to POSME.

The results of this study show that the biodiesels can be used as an alternative fuel in diesel engines.

7. Figure and table

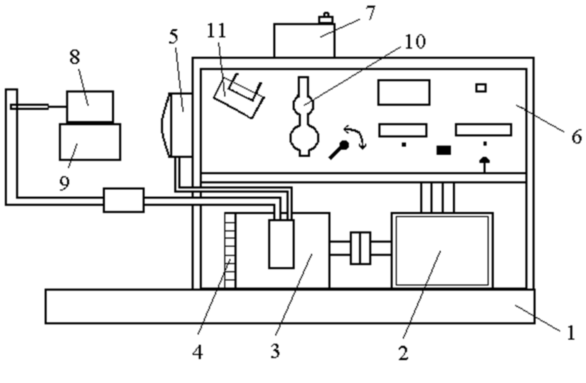

Fig. 1: Schematic layout of the test system (1- engine chassis, 2- electrical dynamometer, 3- diesel engine, 4- engine cooling unit, 5- air tank, 6- control unit, 7- fuel tank, 8- exhaust gas analyzer, 9- digital read out of gas analyzer, 10- fuel measurement burette, 11- manometer)

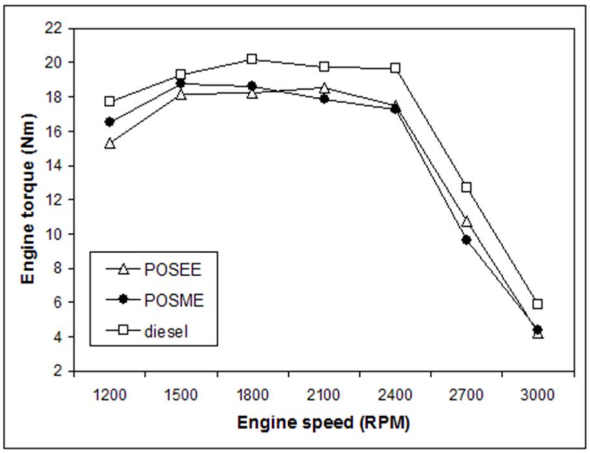

Fig. 2: Engine torque output (Nm) vs. engine rpm for the test fuels.

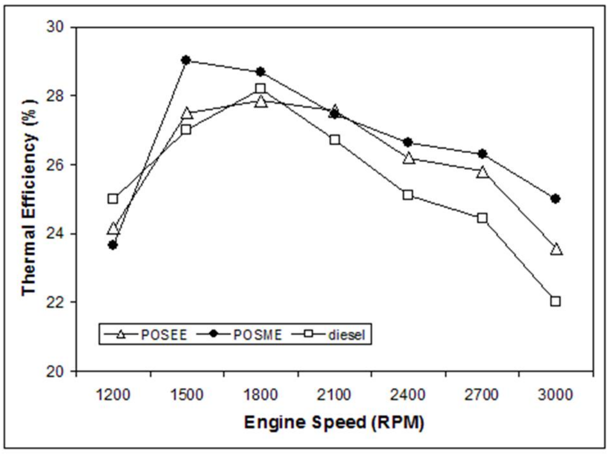

Fig. 5: Thermal efficiency (%) vs. engine rpm for the test fuels.

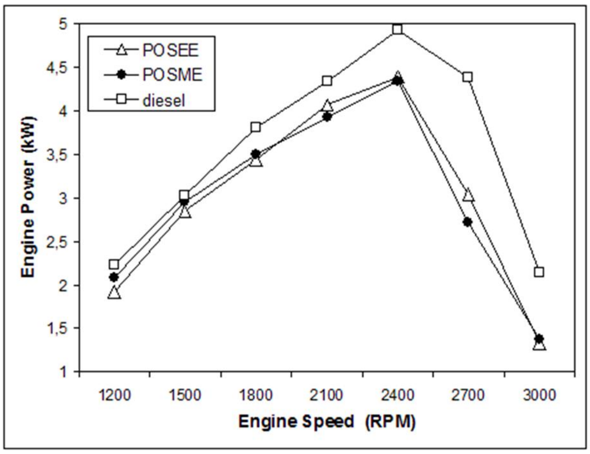

Fig. 3: Engine Power output (kW) vs. engine rpm for the test fuels

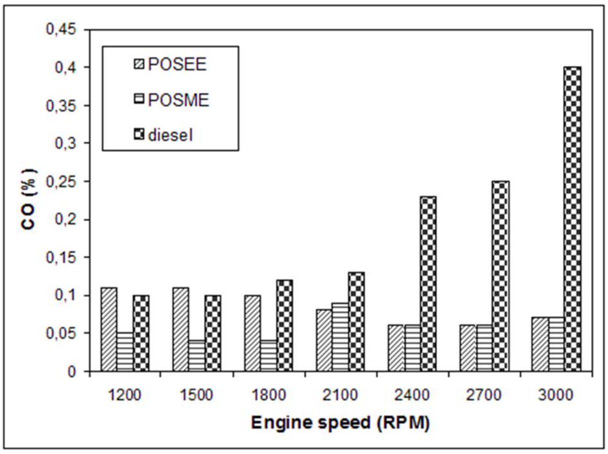

Fig. 6: CO emission (%) vs. engine rpm for the test fuels.

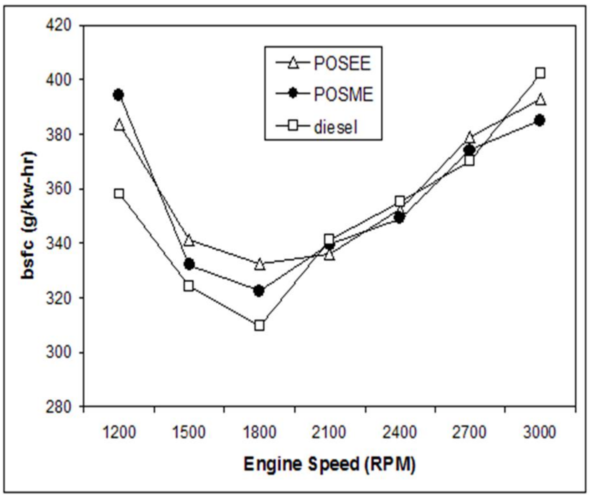

Fig. 4: Brake specific fuel consumption vs. engine rpm for the test fuels.

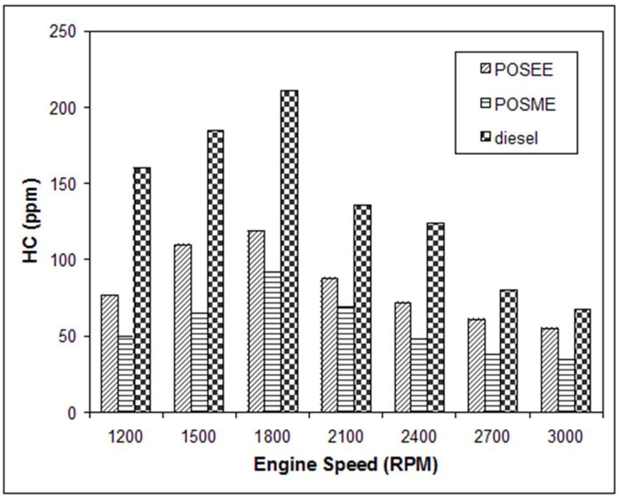

Fig. 7: HC emission (ppm) vs. engine rpm for the test fuels.

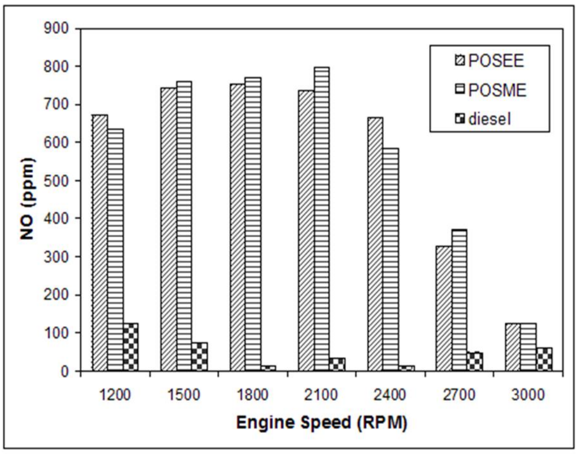

Fig. 8: NO emission (ppm) vs. engine rpm for the test fuels.

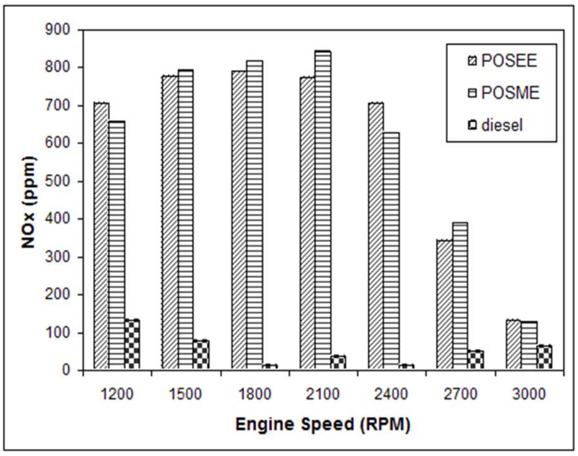

Fig. 9: NO_x emission (ppm) vs. engine rpm for the test fuels.

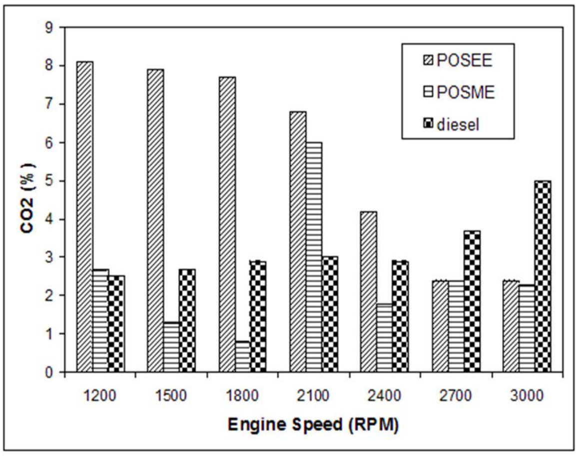

Fig. 10: CO_2 emission (%) vs. engine rpm for the test fuels.

Table 1: Properties of biodiesel products and diesel fuel

Items	POSME	POSEE	Diesel
Appearance	Yellow	Yellow	-------
Specific density (g/cm^3 at 15°C)	0,8866	0,879	0,84
Kinematic viscosity (mm^2/s at 40°C)	4,97	4,92	3,6
Cloud point (°C)	3	0	-15
Flash point (°C)	160,6	150,6	52
High cal. value (kj/kg)	39781	40128	44631
Lower cal. value (kj/kg)	38631	38882	42700

Table 2: Technical specifications of the diesel test engine

Engine	Lombardini
Model	6LD 400
Type	Air couled, four strokes
Combustion	Direct injection
Number of cylinders	1
Cylinder diameter	86mm
Stroke	68mm
Compression ration	18:1
Maximum torque	20 Nm at 2200 rpm
Maximum power	6.25 kW at 3600 rpm

References

(1) Altēn R, Çetinkaya S, Yücesu HS. The potential of using vegetable oil fuels as fuel for diesel engines. Energy Conversion and Management 2001; 42: 529-538.

(2) Dorado MP, Ballesteros E, Arnal JM, Gomez J, Lopez FJ. Exhaust emissions from a Diesel engine fuelled with transesterified waste olive oil. Fuel 2003; 82: 1311-1315.

(3) Antolin G, Tinaut FV, Briceno Y, Castano V, Perez C, Ramirez AI. Optimisation of biodiesel production by sunflower oil transesterification. Bioresource Technology 2002; 83: 111-114.

(4) Kalligeros S, Zannikos F, Stournas S, Lois E, Anastopoulos G, Teas Ch, Sakellaropoulos F. An investigation of using biodiesel/marine diesel blends on the performance of a stationary diesel engine. Biomass and Bioenergy 2003; 24: 141-149.

(5) Al-Widyan MI, Tashtoush G, Abu-Qudais M. Utilization of ethyl ester of waste vegetable oils as fuel in diesel engines. Fuel Processing Technology 2002; 76: 91-103.

(6) Puhan S, Vedaraman N, Sankaranarayanan G, Ram BVB. Performance and emission study of Mahua oil (madhuca indica oil) ethyl ester in a 4-stroke natural aspirated direct injection diesel engine. Renewable Energy 2005; 30: 1269-1278.

(7) Çetinkaya M, Ulusoy Y, Tekin Y, Karaosmanoĵlu F. Engine and winter road test performances of used cooking oil originated biodiesel. Energy Conversion and Management 2005; 46: 1279-1291.

(8) Usta N, Öztürk E, Can Ö, Conkur ES, Nas S, Çon AH, Can AÇ, Topcu M. Combustion of biodiesel fuel produced from hazelnut soapstock/waste sunflower oil

mixture in a Diesel engine. Energy Conversion and Management 2005; 46: 741ï 755.

(9) Usta N. An experimental study on performance and exhaust emissions of a diesel engine fuelled with tobacco seed oil methyl ester. Energy Conversion and Management 2005; 46: (15-16), 2373-2386.

(10) Raheman H, Phadatare AG. Diesel engine emissions and performance from blends of karanja methyl ester and diesel. Biomass and Bioenergy 2004; 27: 393-397.

(11) Kalam MA, Masjuki HH. Biodiesel from palmoil-an analysis of its properties and potential. Biomass and Bioenergy 2002; 23: 471-479.

(12) Ramadhas AS, Muraleedharan C, Jayaraj S. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renewable Energy 2005; 30(12): 1789-1800.

(13) WinLee S, Herage T, Young B. Emission reduction potential from the combustion of soy methyl ester fuel blended with petroleum distillate fuel. Fuel 2004; 83: 1607-1613.

(14) Barnwal BK, Sharma MP. Prospects of biodiesel production from vegetable oils in India. Renewable and Sustainable Energy Reviews 2004; 9: 363-378.

(15) Yücesu HS, Altēn R, Çetinkaya S. Dizel motorlarēnda alternatif yakēt olarak bitkisel yaĵ kullanēmēnēn deneysel incelenmesi. Turk J. Engin. Environ. Sci. 2001; 25: 39-49.

(16) Handmade projects, journey to forever, http:// www.journeytoforever.org

(17) Korus R, Hoffman DS, Bam N, Peterson CL, Drown DC. Transesterification process to manufacture ethyl ester of rape oil. Proceedings of 1st Biomass Conference of the Americas, 1992; 2: 815-826.

(18) Szybist JP, Boehman AL, Taylor JD, McCormick RL. Evaluation of formulation strategies to eliminate the biodiesel NOX effect. Fuel Processing Technology 2005; 86(10): 1109-1126.

(19) Karaosmanoĵlu F. Biyomotorin ve Türkiye. Enerji 2001; 1: 35-38.