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BIODIESEL PRODUCTION FROM RAW COTTONSEED OIL AND ITS PERFORMANCE IN A DIESEL ENGINE

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Abstract

In this experimental work, raw cottonseed oil was converted by KOH-catalyzed transesterification reaction with methyl alcohol to the cottonseed oil methyl ester (biodiesel) and then tested in a single cylinder, four strokes and direct injection diesel engine at the constant engine speed (2000 rpm) under different engine loads. The composition and the fuel-related properties of produced biodiesel were determined by using gas chromatography (GC) and related instruments. An increase in brake specific fuel consumption (BSFC) and decrease in brake thermal efficiency (BTE) for fuel blends were observed compared with diesel fuel. Compared with diesel fuel, exhaust emissions were found to be lower in carbon monoxide, hydrocarbon, nitrogen oxides and smoke with the use of fuel blends. It was concluded that cottonseed oil methyl ester-diesel fuel blends could be substituted for the diesel fuel without any modifications in diesel engines, with better environmental characteristics of fuel blends.

Key Words: Biodiesel, Cottonseed oil, Fuel Properties, Performance, Exhaust Emissions.

1. Introduction

Vegetable oils are becoming a promising alternative to diesel fuel because they are renewable in nature and can be produced locally are environmentally friendly as well [1]. They can be used in diesel engines as a straight replacement fuel for petroleum diesel fuels after pretreatments because of their much higher viscosity. In fact, Rudolph Diesel suggested that vegetable oils would be the future fuel for diesel engines more than a century ago. At that time, since petroleum based fuels had been cheap and plentiful for many years, and because renewable sources of alternative motor fuels such as vegetable oils had been more expensive than oil products they could not compete with oil and petroleum products, and this made engines to work and develop with petroleum products. As for today, significant environmental concerns and the decreasing oil reserves and the fact that vegetable oils are renewable have caused accelerated researches on vegetable oils and fats. However, the use of vegetable oils as fuels for diesel engines is restricted because of their high viscosity. The blending with diesel fuel (dilution), micro emulsification, pyrolysis and transesterification can be used to reduce the vegetable oil viscosity. One of the most common methods used to reduce oil viscosity is called transesterification [2,3]. Hence, the transesterified oils called bio-diesel can be used as alternative fuels in diesel engines without modification and any long-term operational or durability problems, as reported by researchers [4-7].

Generally, the vegetable oils of choice for biodiesel production are those which occur abundantly in the region of testing. For example, soybean oil is of primary interest as biodiesel source in the United States, while many European countries are concerned with rapeseed oil, and countries with tropical climate prefer to utilize coconut oil or palm oil [8]. Among the vegetable oil seeds that can be grown as domestic field crops, cottonseed and sunflower seed are the major productions of Turkey. Therefore, cottonseed oil is expected to become one of bio-diesel sources in countries where cottonseed oil is plentiful such as Turkey, and it may

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become an important alternative fuel. According to the Turkish Stastical Institute (TurkStat), cottonseed has the highest level of the seed production in Turkey compared to other products in 2008, followed by sunflower [9]. Therefore, it is very important to investigate engine performance using biodiesel produced from cottonseed oil, as well as analyzing the exhaust emissions produced.

In the present study, raw cottonseed oil of Turkish origin was converted by KOH-catalyzed transesterification reaction with methyl alcohol to the cottonseed oil methyl ester (biodiesel). Cottonseed oil methyl ester (CSOME) was analyzed by gas chromatography (GC). The fuel-related properties were also determined and compared with specified standards by ASTM D6751 and EN 14214. The biodiesel obtained was then used in a single cylinder, four strokes and direct injection diesel engine. The performance and emission tests were experimentally performed to investigate biodiesel behavior as an alternative diesel fuel.

2. Experimental details

2.1. Biodiesel production from raw cottonseed oil and its characterization

Fatty acid methyl ester of raw cottonseed oil was prepared by alkali-catalyzed transesterification with methyl alcohol in the presence of KOH as catalyst. Raw cottonseed oil from Turkish commercial sources was used to obtain the biodiesel. Raw cottonseed oil is obtained from cottonseeds which are grown in Diyarbakır-Batman, Turkey. For the transesterification reaction, the results of the studies by Demirbaş [8], Rashid et al. [10], Nabi et al. [11] and Aydın and Bayındır [12] were considered. The transesterification process of raw cottonseed oil to produce biodiesel is presented below:

A 1000 ml, three-necked flask equipped with condenser and a thermometer were used for reaction. Raw cottonseed oil (700 g) was heated and kept at constant temperature (60 ºC). An amount of methyl alcohol equal to 20 % of prepared oil was mixed with 0.35% KOH, volumetrically. The mixture was heated and then stirred between 30-40 ^oC until the KOH was completely solved and liquefied in the alcohol. Then the mixture of alcohol and catalyst was added to the cap containing cottonseed oil. To obtain a homogenous mixture of reactants, a magnetic stirrer was used. The mixture of oil-alcohol-catalyzer was heated at permanent temperature of 60±2 ^oC and it was stirred simultaneously at about 1000 rpm in the reaction cap for 2 hours. After 2 hours of reaction time, the products were filled into a washing and separation funnel. The reaction products were separated into two layers, the top one was biodiesel and the bottom one was glycerol. The biodiesel was separated from glycerol. Then sulphuric acid (H_2SO_4) was added the biodiesel for depolarization. The biodiesel was then washed with equal amount of pure warm water to separate the probably remaining alcohol or catalyst from biodiesel. It was then kept for 4 hours in the cap to separate the water. Finally, the biodiesel was heated above 100 ^oC to remove the remaining water from biodiesel fuel.

The obtained biodiesel were characterized by determining its cold filter plugging point, cloud point, kinematics viscosity, density, cetane index, flash point, distillation and heating value. Fatty acid composition of cottonseed oil methyl ester was determined by using chromatography (GC). The fuel-related properties were determined in the fuel analysis laboratory of TUPRAS (Turkish Petroleum Refineries Co.), Batman Refinery, Turkey. GC analysis and heating value were performed in the laboratory of Fuel Analysis at Chemistry Department of Dicle University, Diyarbakır, Turkey. Test instruments and methods are given in Table 1. The fuel-related properties of cottonseed oil methyl ester and diesel fuel are presented in Table 2.The properties of No.2 diesel fuel was obtained from Turkish Petroleum Refineries Co. (TUPRAS).

Table 1 The test instruments and used methods

PARAMETERS	ASTM Test No	Instruments
Kinematic viscosity (mm^2/s)	ASTM D88	Herzog HVM472
Heating value (kJ/kg)	ASTM D240	IKA C2000 Basic Calorimeter
Density (at 15 ^0C) (kg/m^3)	ASTM D1298	Anton Paar DMA5000
Specific gravity	ASTM D1299	Anton Paar DMA5000
Flash point (ºC)	ASTM D93	Herzog HFP360(closed-cup)
Cold filter plugging point (ºC)	ASTM D6371	FPP 5Gs - CFPP/ ISL
Cloud point (ºC)	ASTM D2500	Dortmund 1/Coesfeld D-4600

2.2. Determination of Fatty acid composition by GC

GC analysis was performed in the Laboratory of Fuel Analysis at Chemistry Department of Dicle University, Diyarbakır, Turkey. The cottonseed oil methyl esters (CSOME) was analyzed on a Hewlett-Packard (HP)

6890 gas chromatograph with detector being flame ionization detector (FID) with a BPX 70 capillary column (30 m x 0.25 mm x 0.25 µm film) (%70 Cyanopropyl polysiphonilene-siloxane). The GC work parameters were as follows: the temperature of the injector and the detector was 270 ^{0}C and 280 ^{0}C, respectively. A sample volume of 1.0 µL was injected using split mode (split ratio of 1:50). Gas flow velocities: carrier gas: Helium 0.8 ml/dk (constant flow mode); hydrogen: 30 ml/dk; air: 300 ml/dk. The column (oven) was held at 130 ^{0}C for 1 min and then ramped to 170 ^{0}C at 6.5 ^{0}C/min, 215 ^{0}C at 2.75 ^{0}C/min for 12 min and it was then held at 230 ^{0}C at 40 ^{0}C/min for 3 min. Total time for analyze was 38.8 minute. In the diagnosis of fat acids, methyl esters mixture of fat acids (Sigma-Aldrich Chemicals) was used as a standard. The chromatograms of fat acid methyl esters and total amount of fat acids were obtained on the computer by means of HP 3365 Chem Station software programme. The peaks of the samples analyzed in the chromatogram were diagnosed by comparing all fat acids and methyl esters retention time.

Table 2 The fuel properties of pure biodiesel (CSOME) and diesel fuel (DF)

PARAMETERS	**Diesel Fuel**	**CSOME**
Kinematic viscosity (mm^2/s)	2,72	4,34
Lower Heating value (kJ/kg)	42700	38630
Density (at 15 ^{0}C) (kg/m^3)	825,6	883,9
Specific gravity	826,4	884,7
Flash point (ºC)	62	170
Cold filter plugging point (ºC)	-18	-10
Cloud point (ºC)	-	-1,0
Cetane index (CI)	55,95	55,6
Distillation (%)		
IBP	165	173
10	204	330
50	266	332
90	333	343
EP	365	347

2.3. Engine tests

Experiments were carried out in Engine Test Laboratory of Automotive Department of Technical Education Faculty at University of Batman. The schematic diagram of the experimental setup is shown in Fig. 1. A Rainbow-186, single-cylinder, four-stroke, air-cooled, naturally aspired direct injection diesel engine was used for engine tests. Engine tests were conducted on a BT-140 model hydraulic dynamometer. The basic specifications of the engine are shown in Table 3. The CAPELEC CAP 3200 brand exhaust gas analyzer was used to measure emissions of the test fuels. An infrared temperature measurement device was used to specify exhaust gas temperature.

Table 3 Technical specifications of the test engine

Type of Engine	Rainbow–186 four stroke, air cooled, single cylinder DI diesel engine
Volume	406 cc
Compression Ratio	18/1
Maximum Power	10 HP
Maximum Engine Speed	3600 rpm ±20
Cooling System	Air Cooling
Injection Pressure	19.6±0.49 Mpa (200 ±5 Kgf/cm^2)
Mean Effective Pressure(Mep)	561.6 Kpa (5.73 Kgf/cm^2)
Medium Piston Speed	7.0 m/s (at 3000 rpm)

The fuel blends that were obtained from the addition of 10 % and 20 % of biodiesel to petroleum diesel fuel were named here as CSOME10 and CSOME20, respectively. The series of tests were conducted using each of fuel blends and diesel fuel, with the engine working at loads of 40%, 60% and 80% of the full load. The fueling rate of the engine by gas spindle was set to obtain same torque values at an engine speed of 2000 rpm for all tested fuels. Each test was repeated two times to reduce the experimental uncertainties and the results of the three repetitions were averaged. The accuracy of the measurements and the results of uncertainty analysis of the calculated results are shown in Table 4. In each test, brake torque, brake power, fuel flow rate, exhaust gas temperature and exhaust emissions such as CO, unburned HCs, NO_x and smoke in exhaust were measured. Brake specific fuel consumption and thermal efficiency were calculated from the measured fuel flow rate and heating values using Eqs. (1) and (2).

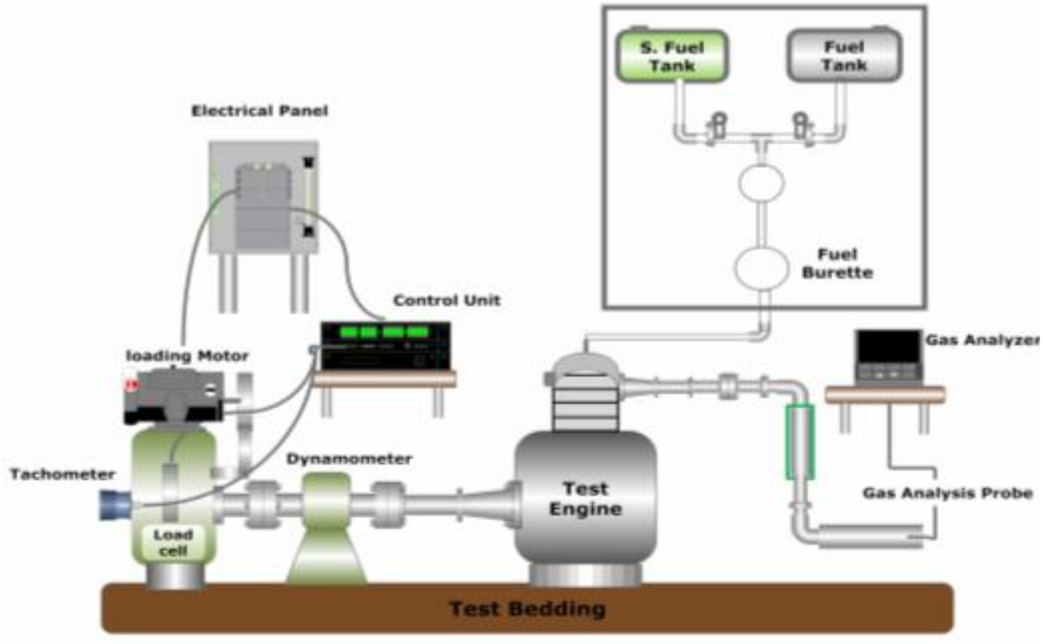

Figure 1 A schematic diagram of the engine setup.

The fuel consumption was measured with burettes with 50 and 100 ml volumes and a stopwatch. The BSFC was calculated using Eq. (1).

$$be = \frac{\dot{v}.\rho.3600}{Pe} \qquad (1)$$

Where *be* is the brake specific fuel consumption (BSFC) as g/kWh, $\dot{v}$ is the flow rate of the fuel as cm^3/s, ρ is the density of the fuel as g/cm^3, and *Pe* is the brake power in kW. The brake thermal efficiency is defined as the actual brake work per cycle divided by the amount of fuel chemical energy as indicated by the fuel's lower heating value. Thus, the brake thermal efficiency (BTE) can be calculated using Eq. (2).

$$\eta_e = \frac{3{,}6x10^6}{be.Hu} \qquad (2)$$

Where b_e is the BSFC in g/kWh; H_u is the lower heating value of the fuels in kJ/kg.

Table 4 The accuracy of the measurements and the uncertainties in the calculated results

Parameter	Measuring range	Accuracy
Load	250 Nm max.	±2 Nm
Speed	7500 rpm max.	±25 rpm
Time	-	±0.1s
Temperatures	(-32 - +545°C)	±1%
HC	0-20000 ppm	±1 ppm
CO_2	0-20%	±0.1%
CO	0-15%	±0.001%
O_2	0-21.7%	±0.01%
NO_x	0-5000 ppm	±1 ppm
Smoke	0 - 100%	±0.1%
Calculated results		**Uncertainty**
BSFC		±2.5% max.
BTE		±2.5% max.

3. Results and discussion
3.1. The gas chromatograph analysis

Table 5 lists the FAME composition for the biodiesel fuel produced from raw cottonseed oil. From gas chromatograph analysis, it was found that the biodiesel produced from raw cottonseed oil contains eight fatty acids. The most abundant composition was linoleic acid methyl ester with the content of 57.1%. Palmitic acid (20.9%) was the next most abundant FA, followed by oleic acid (17.9%). It was also seen that the cottonseed oil methyl ester contained the more amount of total unsaturated FA (75.7%). The polyunsaturated FAs are about 57.3%, and also monounsaturated FAs are about %18.4, as shown in Table 5.

Table 5 Fatty acid composition of biodiesel by using GC

Fatty acid type	Carbon chain	Ester of fatty acid (%)
Linoleic	C18:2	57.1
Palmitic	C16:0	20.9
Oleic	C18:1	17.9
Stearic	C18:0	2.43
Mirictic	C14:0	0.65
Palmitoleic	C16:1	0.46
Trideconoic	C13:0	0.29
Linolenic	C18:3	0.18
Total		**99.9**
Σ Saturated acids (SFA)		24.3
Σ Unsaturated acids (UFA)		75.7
Σ Monounsaturated acids (MUFA)		18.4
Σ Polyunsaturated acids (PUFA)		57.3

3.2. Fuel-related properties

The fuel-related properties of cottonseed oil methyl ester and diesel fuel are presented in Table 2. Table 2 shows that the viscosity, density and flash point of CSOME are higher than that of diesel fuel and they are in accordance with the specified standards by ASTM D 6751 and EN 14214. A more important measure of diesel fuel cold-flow operability is the cold filter plugging point (CFPP), which more accurately reflects the cold-flow operability of the fuel [13]. In this study, the CFPP of CSOME was -10 °C, and the cloud point (CP) was also -1 ^{0}C. Cottonseed oil methyl ester with large amounts of unsaturated FA showed better cold-flow operability than more saturated fatty acid methyl esters such as beef tallow biodiesel (CFPP, 15 ^{0}C) [14] and palm oil biodiesel (CFPP, 12 ^{0}C) [15]. The cetane index for the CSOME (55.56) was slightly lower than that of the diesel fuel (55.95).

The cottonseed oil methyl ester has higher distillation temperatures than that of diesel fuel, as shown in Table 2. The initial boiling point (IBP) of CSOME is 173 ^{0}C while the IBP of diesel fuel is 165 ^{0}C. Contrary to the initial distillation temperature, the final distillation temperature for CSOME was lower than that of diesel fuel. Moreover, maximum temperature must be 360 ^{0}C according to ASTM D6751 standard specification for 90% distillation fraction. In this study, 90% distillation fraction temperature is below this value for CSOME. The amount of distilled volume versus temperature clarifies that the fuel samples were distilled homogenously, smoothly and gradually with temperature increases. This means that the fuel particles in the cylinder are combusted homogenously, gradually and completely

3.3. Engine performance and exhaust emissions

An experimental work on the performance and exhaust emissions of a direct injection compression-ignition engine when operating on blends of cottonseed oil methyl ester with diesel fuel has been studied for parameters such as engine performance and exhaust emissions. Experimental results were plotted against the engine load at constant engine speed and presented on Figures 2-8.

3.3.1. Brake specific fuel consumption (BSFC) and Brake thermal efficiency (BTE)

The effect of fuel blends on the BSFC and BTE are shown in Figure 2 and 3, respectively. The BSFC values for fuel blends were found to be slightly higher than those of diesel fuel, while BTE values were lower than those of the diesel fuel. This is the expected result due to the lower heating value of the cottonseed oil methyl ester compared to that for diesel fuel. As a matter fact, fuels that have lower heating value than for diesel fuel need that a larger amount of fuel be injected into the combustion chamber to produce the same power. Since BTE is inversely proportional to BSFC and the heating value, it is calculated as lower than diesel fuel. At the engine speed of 2000 rpm and a load of 80%, the brake thermal efficiencies for diesel fuel, CSOME10 and CSOME20 were calculated as ~25%, 24.8% and 24.1% and respectively. The obtained results in Figures 2 and 3 agree well with those of other researchers [11,12,16] who investigated the performance of the cottonseed oil methyl ester or its blends with diesel fuel in a diesel engine.

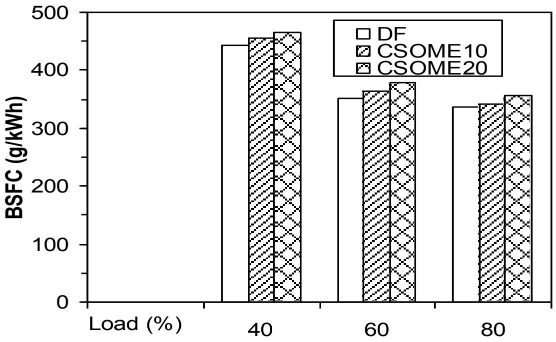

Fig. 2 The comparison of BSFC

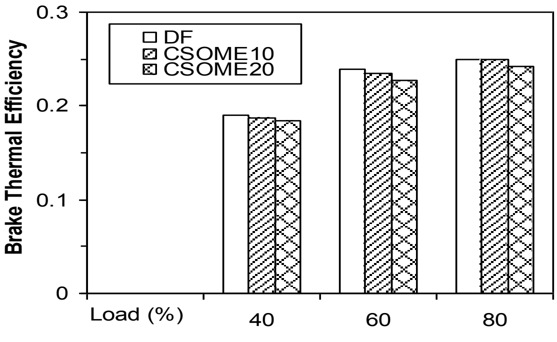

Fig. 3 The comparison of BTE

3.3.2. Exhaust emissions and exhaust gas temperature (EGT)

Figs. 4-8 show the gaseous emissions, exhaust gas temperature and smoke values for the diesel fuel and fuel blends. The change in NO_x emissions with respect to load for tested fuels is presented in Fig. 4. In the figure, it can be seen that the NO_x emissions increased with the increase of the engine load for all tested fuels. As the load increases, more fuel is required to compensate the high load; the more fuel is combusted at high load than that at low loads, leading to the increase of gas temperature in engine cylinder. As a result, there is higher NO_x formation in the engine, which is sensitive to temperature increase. From the figure 4, it can also be seen that the NO_x emissions from fuel blends are lower than that of diesel fuel. The lower heating value (LHV) of the fuel blends may be given as a reason for less NO_x emissions. For the exhaust gas temperature, the same trend can be seen from the figure 5, however, at the engine load of 40%, fuel blends gave the higher EGT values than that of diesel fuel. This may be due to the oxygen present in blends which makes the combustion more complete when the engine works at low load. Figs. 6 and 7 show the results of carbon monoxide (CO) emissions and smoke opacity of the diesel engine fuelled by three different fuels. In the figures, it can be seen that these emissions are low when the engine works at the low and medium loads; and they are high at the high engine loads. The variation in unburned HC emissions is also given in Fig.8. According to Fig. 8, diesel fuel produced the higher amount of HC than fuel blends for all engine loads, except at engine load of 40% where CSOME gave the highest. The excess oxygen contained in the biodiesel thereby in fuel blends have taken a hand in reduction of CO, HC and smoke emissions of the test engine when operation with CSOME10 and CSOME20 fuel blends. Besides, cetane number and boiling point of fuel blends were similar to those of diesel fuel, thus improve combustion by providing a similar ignition delay and combustion environment.

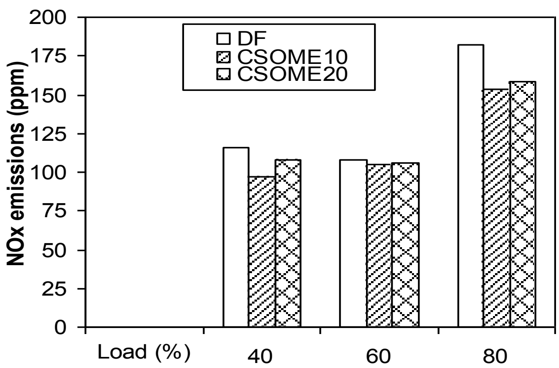

Fig. 4 NO_x emissions

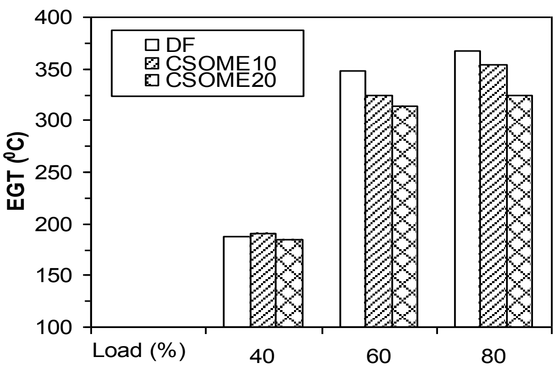

Fig.5 The comparison of EGT

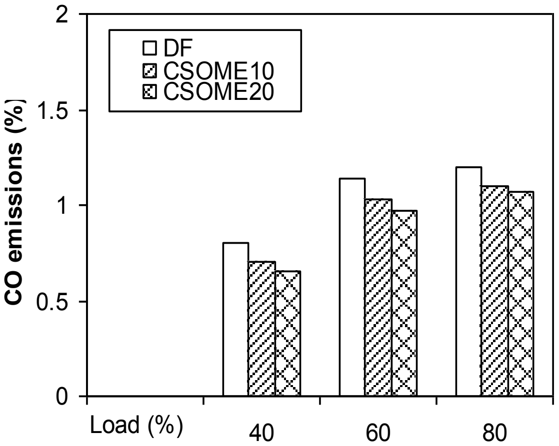

Fig. 6 CO emissions

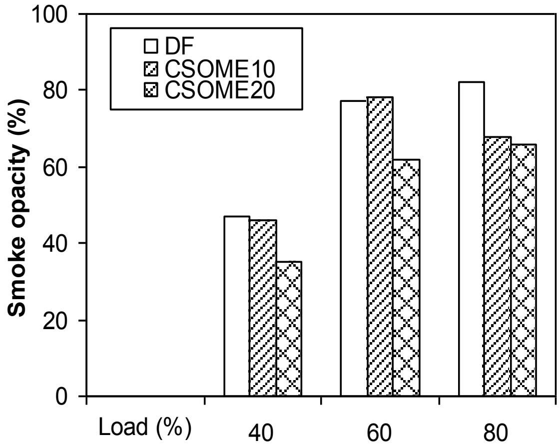

Fig.7 Change in smoke in exhaust

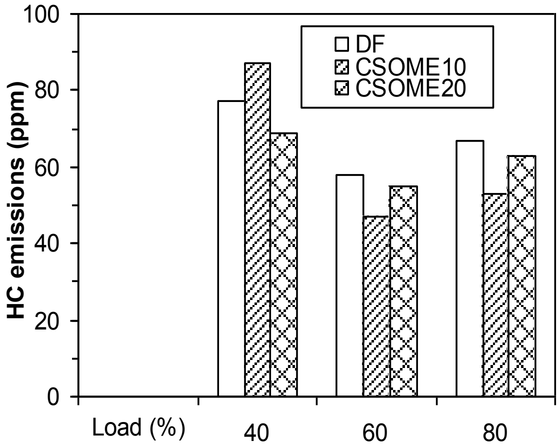

Fig.8 Hydrocarbon (HC) emissions

4. Conclusion

General findings in this study can be listed as follows:

- According to GC analysis, the biodiesel produced in this study contains eight fatty acids. The most abundant composition was linoleic acid methyl ester with the content of 57.1%. Palmitic acid (20.9%) was the next most abundant FA, followed by oleic acid (17.9%). Cottonseed oil methyl ester has more amount of total unsaturated FA (75.7%).
- The fuel-related properties of cottonseed oil methyl ester were within the specified standards by ASTM 6751 and EN 14214. The cottonseed oil methyl ester and diesel fuel have comparable cetane index. Importantly, the final boiling point of the cottonseed oil methyl ester was found to be lower than that of No. 2 diesel fuel. This affirmative property led to a more complete combustion for the cottonseed oil methyl ester, as it was supported by the results of the emission test in our study.
- The brake specific fuel consumption of the fuel blends was higher than those of diesel fuel, while brake thermal efficiency values were lower than those of the diesel fuel.
- The significant improvement in reduction of carbon monoxide (CO), hydrocarbons (HCs) and smoke were found for fuel blends. The NO_x emissions were also lower for fuel blends than that of diesel fuel.

From the experimental results, cottonseed oil methyl ester-diesel fuel blends could be substituted for the diesel fuel without any modifications in diesel engines, with the better environmental characteristics of fuel blends.

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