Fuel xxx (xxxx) xxx-xxx

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com

ELSEVIER

Full Length Article

Experimental studies on the biodiesel production parameters optimization of sunflower and soybean oil mixture and DI engine combustion, performance, and emission analysis fueled with diesel/biodiesel blends

Medhat Elkelawy [a, *], Hagar Alm-Eldin Bastawissi [a], Khaled Khodary Esmaeil [a], Ahmed Mohamed Radwan [a], Hitesh Panchal [b], Kishor Kumar Sadasivuni [c], Deepalekshmi Ponnamma [c], Rashmi Walvekar [d]

[a] *Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt*
[b] *Mechanical Engineering Department, Government Engineering College Patan, Gujarat, India*
[c] *Center for Advanced Materials, Qatar University, Qatar*
[d] *Chemical Engineering Department, Taylors University, Malaysia*

ARTICLE INFO

Keywords:
Sunflower
Soybean
Oil
Biodiesel
Transesterification
Colour
Oxidation
Contaminates
Filtration
Distillation

ABSTRACT

The influence of diesel/biodiesel blends on engine combustion, performance, and exhaust gas emissions have carried out experimentally at different engine loads and constant speed of 1400 rpm. Volumetric percentage of diesel/biodiesel blends: D70B30 (70% diesel–30% biodiesel), D50B50 (50% diesel–50% biodiesel) and D30B70 (30% diesel–70% biodiesel) were prepared to power a single cylinder diesel engine. The engine results as compared to diesel fuel, show a reduction in the rate of change of CO by 33.8% for D50B50. The slight decrease in maximum cylinder pressure for higher percentage of biodiesel blends due to low calorific value of biodiesel and lower ignition delay. The reduction in HRR for biodiesel blends as compared to diesel fuel. HRR was about 31.7, 52.4 and 63.5 (J/deg) for 10%, 30% and 60% of maximum engine power. The highest reduction in HC emissions concerning diesel fuel was about 4.18% for D30B70. NOx emissions of biodiesel blends were higher than diesel. Exhaust oxygen (EO) emissions for D30B70 was about 0.98% higher than diesel. Exhaust gas temperature (EGT) has observed for all biodiesel blends. Brake specific fuel consumption (BSFC) is increased until it reaches 11.43% for D30B70. A consequent reduction in brake thermal efficiency (BTE) and brake specific energy consumption (BSEC) is observed for all biodiesel blends.

Nomenclature

BTE	Brake thermal Efficiency
EGT	Exhaust gas Temperature
ASTM	American society for testing and materials
BSFC	Brake specific fuel consumption
CO	Carbon monoxide
HC	Hydrocarbon
HRR	Heat release rate

1. Introduction

Energy efficient conversion requires fuel to have specific properties and to be suitable engine operating conditions. Researchers found that biodiesel meet these requirements with minimal engine modifications. Biodiesel can be produced from vegetable oils, animal fats species, give the same thermal energy as compared to diesel fuel. Besides, it does not contain sulfur, minerals and produces low rates of engine emissions due to high oxygen content. High intensity of biodiesel helps in the self-lubricating of the engine mechanical parts. Biodiesel is mono-alkyl esters of long chain fatty acids can be prepared from acyl-glycerol (natural triglyceride) which exist in vegetable oils. It can be achieved via a transesterification process with short-chain alcohols in the presence of a catalyst. Homogeneous transesterification is the conventional method to produce biodiesel [1,2].

Numerous researches have carried out to optimize transesterification reaction variables to maximize methyl ester yield. Each reaction variable was studied separately, which affect biodiesel yield produced from vegetable oil via alkaline catalyzed transesterification [3,4]. Optimum conditions were found to be 6:1 methanol/oil ratio, 60 °C reac-

* Corresponding author.
Email address: Engineerhitesh2000@gmail.com (M. Elkelawy)

https://doi.org/10.1016/j.fuel.2019.115791
Received 17 May 2019; Received in revised form 23 June 2019; Accepted 8 July 2019
Available online xxx
0016-2361/ © 2019.

Table 1
physicochemical properties and composition of Sunflower oil, and Soybean oil.

Property	Soybean oil	Sunflower oil
Palmitic acid C16:0	11.8	6.3
Stearic acid C18:0	3.2	2.95
Oleic acid C18:1	23.5	18.5
Linoleic acid C18:2	55.6	66.1
Linolenic acid C18:3	6.44	0.07
Density (gm/cm^3)	0.91	0.92
Kinematic viscosity (cst, at 40 °C)	32.9	32.6
Acid value (mg KOH/g)	0.2	0.22
Flashpoint (°C)	255	275
Heating value (MJ/kg)	39.6	39.6

Table 2
Specifications and sensitivity of the magnetic stirrer hot plate.

Model	MS-H-S circular-top analog magnetic hotplate stirrer
Working plate dimension (mm)	Φ135
Work plate material	Stainless steel cover with ceramic
Motor type	Brushless DC motor
Motor input power (W)	180
Motor output power (W)	100
Power (W)	530
Heating output (W)	500
Voltage (V)	100–120/200–240
Frequency (Hz)	50/60
Stirring positions	1
Max. stirring quantity (H_2O)(L)	20
Max. magnetic bar (length)(mm)	80
Speed range (rpm)	0–1500
Speed range resolution (rpm)	±1
Speed display	Scale
Temperature display	Scale
Heating temperature range (°C)	Room Temp. –340
Over-temperature protection (°C)	350
Temperature display accuracy (°C)	±0.5
Protection class	IP42
Dimension (W*D*H)(mm)	160*280*85
Weight (Kg)	2.8
Permissible ambient temperature (°C)	0–40
Permissible ambient humidity (RH)	80%

tion temperature and 1% (w/w) catalyst concentration with the agitation of 600 rpm for 120 min of the reaction time. The obtained results illustrate that the optimum yield was 97.1% [5]. Therefore, optimizing biodiesel production variables from waste cooking oil (WCO) have investigated analytically and experimentally. Results show that with the analytical method, optimum conditions was 9:1 methanol/oil molar ratio, 1% by wt. NaOH, 50 °C reaction temperature at 90 min of the reaction time. Experiments showed that 6:1 methanol/oil molar ratio is more suitable, which resulted in 89.8% conversion efficiency at optimal conditions [6]. Biodiesel yield from WCO was 88–90% at 7:1–8:1 methanol/oil ratio range, the temperature of 30–50 °C and KOH concentration of 0.75% by wt [7]. Effect of reaction parameters on biodiesel yield produced from Castor oil was illustrated. Methyl ester yield was 95% by wt. at 1% wt. KOH, 9:1 M/O ratio, the reaction time of 30 min and 60 °C. However, it was found that yield at 30 °C was compatible with the yield at 60 °C [8]. Factors affecting the production of methyl ester from rapeseed oil has optimized. The optimum yield was 78.6% at 6:1 methanol/oil ratio, 60 °C reaction temperature, 0.3% by wt: NaOH and 60 min reaction time [9]. Parameters affect transesterification of refined cottonseed oil using batch mode was optimized using response surface methodology with an optimal yield of 96%. Optimal condition was 55 °C reaction temperature, 60 min reaction time,

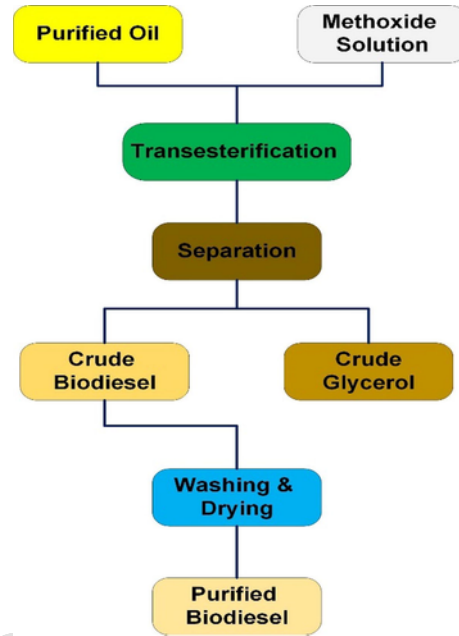

Fig. 1. Schematic of biodiesel production steps.

Table 3
Physicochemical properties of diesel and biodiesel.

Property	Diesel	Biodiesel	ASTM standards	Limits	Units
Specific gravity at 15 °C	0.83	0.88	D 1298	0.86–0.9	–
Kinematic viscosity (at 40 °C)	2.75	4.7	D 445	1.9–6.0	mm^2/s
Pour point	−12	−9	D 97	−15–10	°C
Cloud point	0	7	D 2500	−3–12	°C
Flashpoint	50	160	D 93	130 min	°C
Fire point	61	167	D 93	–	°C
Acid value	0.15	0.22	D 664	0.80 max	mg KOH/g
Cetane number	54	62	D 976	47 min	–
Calorific value	43	37.5	D 240	39–43	(MJ/kg)
Copper strip corrosion	1a	1a	D 130	Class 3	–
Carbon residue	0.014	0.0312	D 524	0.05 max	(wt.%)
Ash content	0.013	0.016	D 129	0.02 max	% by mass
Sulfur content	0.154	0.00	D 5291	–	(wt.%)

The carbon residue shall be run on the 100% sample.

0.6% KOH concentration and constant mixing speed [10]. Statistical analysis (central composite design) was utilized for predicting the optimum yield. Optimum biodiesel yield from lard oil was 96.2% and 96% analytically and experimentally, respectively. Obtained results ware 65 °C reaction temperature, 1.25% catalyst loading, 40 min of the reaction time and methanol/oil ratio of 6:1 with mixing the speed of 250 rpm [11]. Process parameters were optimized for biodiesel production from mixed feedstock using multi-variant empirical model. Results identified that methanol, followed by catalyst loading, has the most significant effect on biodiesel yield. Optimized conditions result in yield is about 98% [12]. Small-scale alkaline transesterification carried out on fish oil, where process parameters optimized by using central composite rotational design method. Optimum reaction parameters values of 0.7% NaOH, reaction temperature of 54 °C and 11.7:1 ethanol/oil molar ratio. Optimal ethyl ester yield was 96.41% [13]. Analytical investigation of reaction variables and it has a significant impact on the yield of ethyl ester produced from refined soybean oil. It was observed

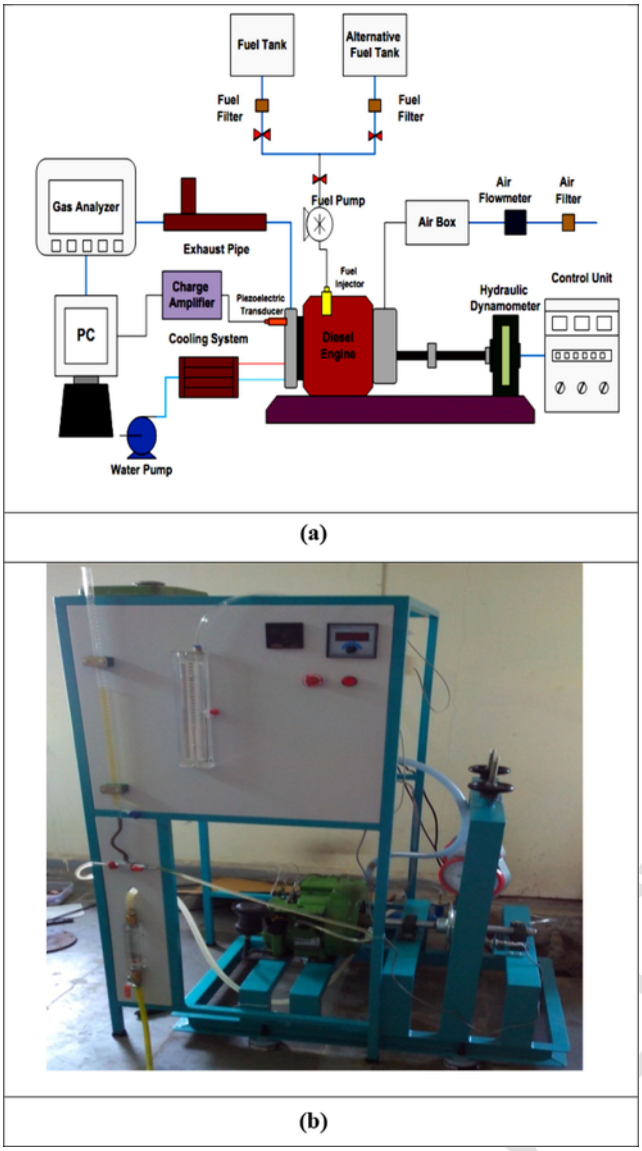

Fig. 2. Engine test-rig; a) Schematic diagram and b) Actual test rig of the engine setup.

Table 4
Specifications of the test engine.

Model	ZS, 1100
Engine type	DI-diesel engine, natural aspirated, four strokes, horizontal type
Cylinder number	Single cylinder
Bore (mm)	100
Stroke (mm)	115
Displacement (L)	0.903
Maximum output (hp)	16
Engine speed (r/min)	2200
Cooling system	Water cooled
Net. Weight (Kgs)	160
Starting mode	Hand starting

that the effect of ethanol/oil ratio was equivalent to the effect of concentration of alkalis on biodiesel yield. However, there was a limited effect as reaction temperature increases. Also, yield decreases significantly at higher catalyst concentration due to soap formation. Results

Table 5
specifications, error, and resolution of gas analyzer.

Parameter	Measurement range	Relative Error	Resolution
HC	(0–1000)*10^{-6} (ppm)	±5%	1*10^{-6} (ppm)
CO	(0–20)*10^{-2} (Vol. %)	±5%	0.01*10^{-2} (Vol. %)
O2	~5000 (Vol. %)	±5%	0.01*10^{-2} (Vol. %)
CO2	(0–10)*10^{-2} (Vol. %)	±5%	0. 1*10^{-2} (Vol. %)
NOx	0–5000 (ppm)	±4%	1*10^{-6} (ppm)

Table 6
Uncertainties of measured and calculated parameters.

Calculated parameters	Percentage uncertainties
BTE	±1%
BSFC	±1.5%
BSEC	±1.5%
Brake power	±0.5%

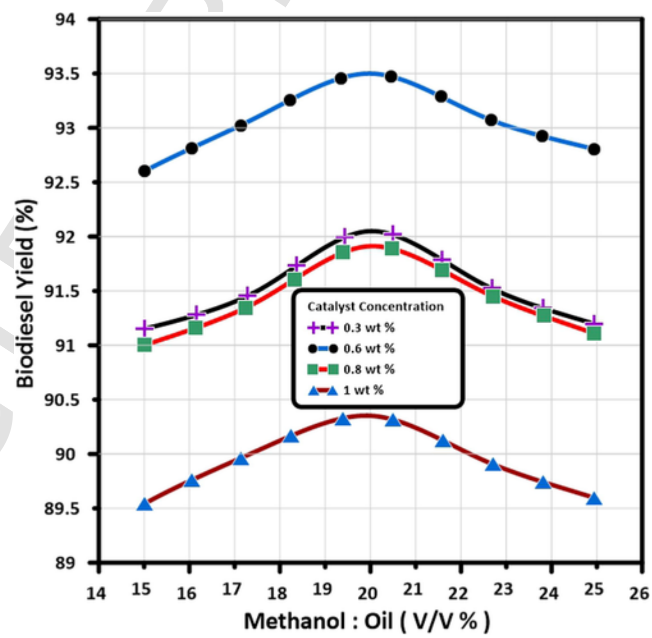

Fig. 3. Methanol to oil ratio with catalyst loading effect on yield at 500 rpm, 60 min reaction time, and 60 °C reaction temperature.

showed that optimum ethyl ester yield was 97.2% at optimum reaction conditions [14]. Parameters that influence the transesterification of used frying oil was varied to achieve the best ethyl ester properties. Ethanol/oil molar ratio of 12:1, 1% KOH and temperature of 78 °C provided biodiesel with the best properties [15]. Transesterification parameters of Pithecellobium dulce seed oil (PDSO) has been optimized by using based Box-Behnken design (BBD). An optimized yield was found to be 93.24% at 0.8% wt. KOH, reaction temperature of 60 °C, 1:6 M ratio and 90 min as reaction time. Also, there was good conformity between predicted yield 93.24% and experimental yield 92.75% [16]. The optimized yield of FAME produced from hazelnut, sunflower, and hybrid feedstocks (50:50 v/v) was found to be 97.5%, 97.3% and 97.9%, respectively. Hybrid feedstock show high yield that indicated that for any particular oil, the reaction was not selective [17].

Many researchers conducted analytical and experimental studies on the effect of biodiesel and its blends usage on engine performance and exhaust gas emissions compared to diesel fuel [18]. The effect of using biodiesel produced from Karanja oil and its blends was investigated on the performance and exhaust emissions parameters concerning pure diesel. It was found that for different engine loads and different blends

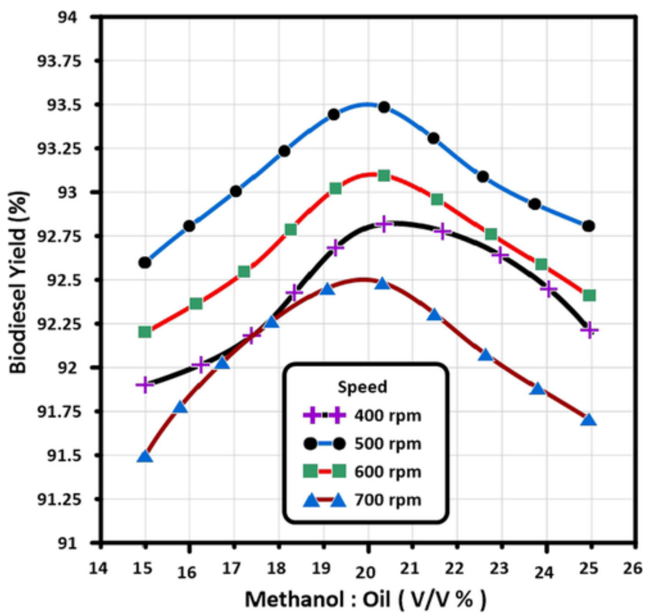

Fig. 4. Methanol to oil ratio with mixing speed effect on yield at 0.6 wt% catalyst loading, 60 min reaction time and 60 °C reaction temperature.

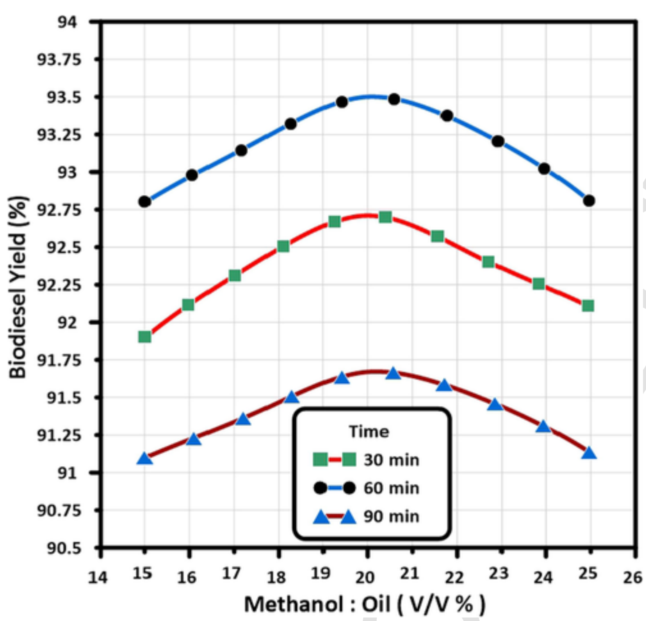

Fig. 5. Methanol to oil ratio with reaction time effect on yield at 0.6 wt% catalyst loading, 500 rpm and 60 °C reaction temperature.

(5%, 10%, 20%, 30% and 100%); BTE decreased by 3–5%, CO, CO2, UBHC and smoke emissions reduced as compared to diesel fuel. However, NOx emissions were higher than diesel [19]. The effect of Pithecellobium dulce biodiesel blends of "PDBD5, PDBD10, and PDBD20" on engine performance and emissions were discussed experimentally. The experimental analysis showed that PDBD20 lower CO, HC, and NOx emissions by 19.64%, 17.64%, and 6.73%, respectively at full load compared to diesel fuel.

Furthermore, CO2 and smoke slightly increased. BSFC for PDBD20 were higher by 9.565% than diesel fuel. However, BTE lowered by 4.34% for the same blended ratio [20]. Performance and emissions of biodiesel produced from two different kinds of WCO used in a single cylinder diesel engine were characterized. Obtained results from B5 and B10 show that BSFC increased up to 4% and decreased BTE up to 2.8%. However, total HC and smoke emissions reduced for all load

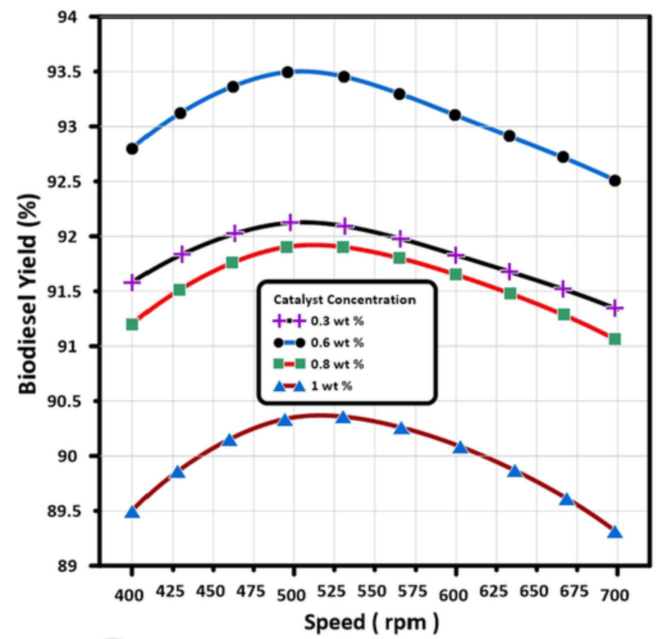

Fig. 6. Mixing speed with catalyst loading effect on yield at 20 V/V% methanol: oil ratio, 60 min reaction time and 60 °C reaction temperature.

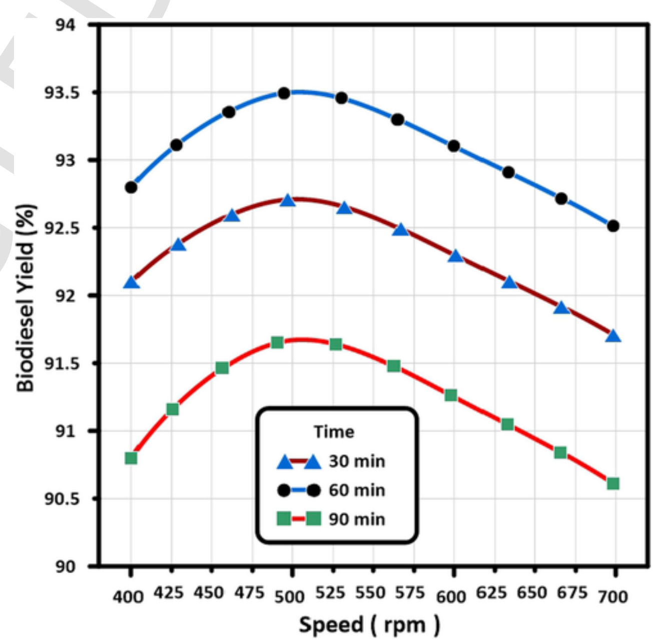

Fig. 7. Mixing speed with reaction time effect on yield at 20 V/V% methanol: oil ratio, 0.6 wt% catalyst loading and 60 °C reaction temperature.

conditions. CO emissions didn't show any significant change for both low and medium engine loads. Also, There was a slight increase in CO2 and NOx emissions [21].

A comprehensive study was made to investigate of the effect of Karanja biodiesel blends of "B5, B10, B15, B20, B25, B50 and B100" on the performance and emission characteristics of the direct injection diesel engine. It was observed that all biodiesel/diesel blends decrease ignition delay period, which resulted in smooth engine operation and pressure rise at less rate. CO, HC, and smoke emissions reduced with increasing biodiesel ratio up to B100 at rated load. Additionally, NOx emission increased in the range of 1.4–22.8% for all blends. BSEC increased at both lower and rated load. However, it slightly decreased at a load of 50%, 75%, and 90%. BTE was reduced for biodiesel blends as

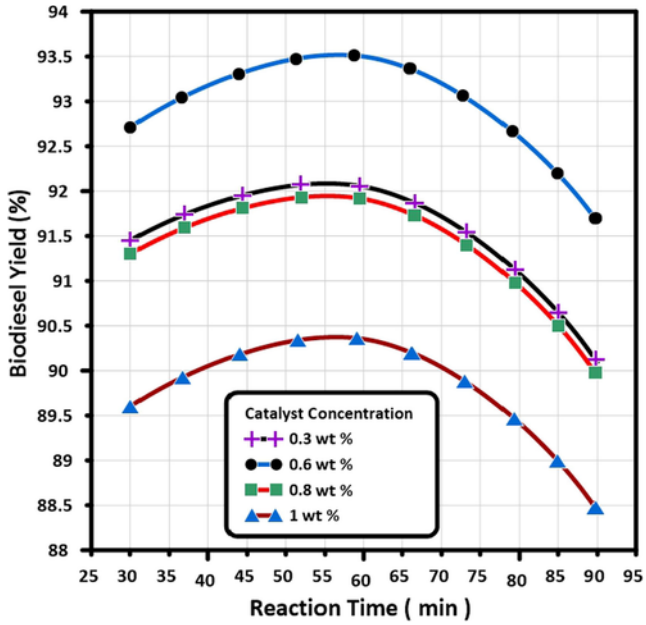

Fig. 8. Reaction time with catalyst loading effect on yield at 20 V/V% methanol: oil ratio, 500 rpm and 60 °C reaction temperature.

compared to diesel fuel [22]. The experimental analysis focused on the study the effect of powering direct injection diesel engine with pure biodiesel produced from WCO and its blends on engine emissions. The obtained experimental result shows an increase in BSFC and decrease in BTE by using biodiesel blends as compared to pure diesel as baseline fuel.

EGT, CO2 and NOx emissions for biodiesel blends were higher than diesel fuel. However, a reduction in CO, HC and smoke emissions was observed for all biodiesel blends [23,24]. The experimental investigation was made on the performance and exhaust emissions of single cylinder diesel engine powered by soybean biodiesel blends of "B10, B20 and B50", for different engine speed. According to the results, a decrease in torque was observed, where BSFC increased. Biodiesel blends made a significant reduction in CO and HC emissions. However, there was an increase in both NOx and CO2 emissions [25]. Performance and emission characteristics of single cylinder diesel engine powered by diesel, rapeseed oil biodiesel and its blends were analyzed. At maximum load condition BSEC, EGT was higher for all biodiesel blends as compared to diesel fuel. However, BTE shows a reduction with increasing blending ratio as results showed that for B25, BTE was 26.38% lower than diesel fuel. Results indicated that for B25, HC and CO emissions reduced by 15.4%, 7.6%, respectively at maximum brake power as compared to diesel.

Furthermore, NOx emission for B25 was 14.4% higher in comparison with diesel. Also, Smoke density showed an increment with both increasing engine load and biodiesel ratio. Experimental results illustrated B25 can be used in a diesel engine without any modification [26].

The present work main objective is to clear the transesterification and purification process used to produce biodiesel from sunflower and soybean oil mixture. Optimize the parameters that have a significant effect on biodiesel yield. Furthermore, study the effect of DI70BO30, DI50BO50, and DI30BO70 on a single cylinder diesel engine performance and emissions.

2. Materials and methods

2.1. Biodiesel production process

The mixture of (50% sunflower and 50% soybean oil) by volume was purchased from the local market, and its properties are shown in Table 1.

A catalyzed transesterification using (NaOH) and methanol of (>99% purity) was carried out on a small scale. A magnetic stirrer hot plate, which consists of a speed and heater controller used for methyl ester production process. Specifications and sensitivity of the magnetic stirrer hot plate are shown in Table 2.

One litre of the oil mixture was heated and filtered. Treated oil and a pre-prepared methoxide (200 mL methanol and 5 gm of NaOH) solution were placed into a dry beaker. Reacted mixture was blended with constant mixing speed of 500 rpm for one hour at constant heating of 60 °C. After one hour, the reacted mixture was poured into a separation funnel and allowed to settle for 24 h. Two layers were formed due to the density difference between biodiesel and glycerol, where biodiesel was the top layer, and glycerol was at the bottom. Biodiesel was poured to a beaker after glycerol separation and was heated up to 70 °C for methanol removal. After methanol removal, biodiesel was transmitting into a small vessel where it was washed by hot water (at 80 °C) at biodiesel/water ratio of 1:1 with moderate agitation. The mixture was transferred into a separation funnel. The washing step used to remove any trace of methanol or catalyst in the sample, and it was repeated until the pH value of seven was achieved. Moisture removal was carried out by heating biodiesel above 100 °C. Finally, biodiesel yield was calculated, where it was stored into a clean and dry container. Fig. 1 shows a schematic diagram of the biodiesel production steps. The effects of catalyst loading, methanol/oil ratio, mixing speed, and reaction time was investigated by varying two parameters and fixed all other conditions under atmospheric pressure.

Biodiesel obtained had a golden yellow colour, and its properties were estimated according to ASTM D 6751, as shown in Table 3. The obtained results showed that the biodiesel flash point was 160 °C, which makes it, secure for handling and storage. Also, the value of The Rams bottom carbon residue test is within the ASTM limits. The calorific value of biodiesel was lower than diesel fuel due to oxygen content existence. The corrosiveness of biodiesel on engine's copper parts is identified by copper strip corrosion test. The result of the experiment was "1a" for biodiesel.

2.2. Preparation of diesel/biodiesel blends

Biodiesel produced from sunflower and soybean oil mixture was mixed with pure diesel at three different volumetric ratios of (70% diesel fuel + 30% biodiesel) D70B30, (50% diesel fuel + 50% biodiesel) D50B50, and (30% diesel fuel + 70% biodiesel) D30B70. Pure diesel and purified biodiesel were mixed by magnetic stirrer at a rate around 1000 rpm for two continuous hours of operation.

2.3. Engine setup and experiment procedure

Experiments were carried out on a single cylinder naturally aspirated and water cooling direct injection diesel engine. Fig. 2(a) shows a schematic diagram of the engine setup, while Fig. 2(b) shows the direct photograph of the test engine components and measuring instruments. Table 4 shows the detailed engine specifications.

The hydraulic dynamometer has connected to a test engine to achieve different engine varying loads. "HPC500/400" automotive emission analyzer was used for quantifying exhaust gas emissions such as CO, CO_2, NO_X, O_2, and HC. Gas analyzer specifications, error, and resolution are shown in Table 5. K-type Thermocouples were used to

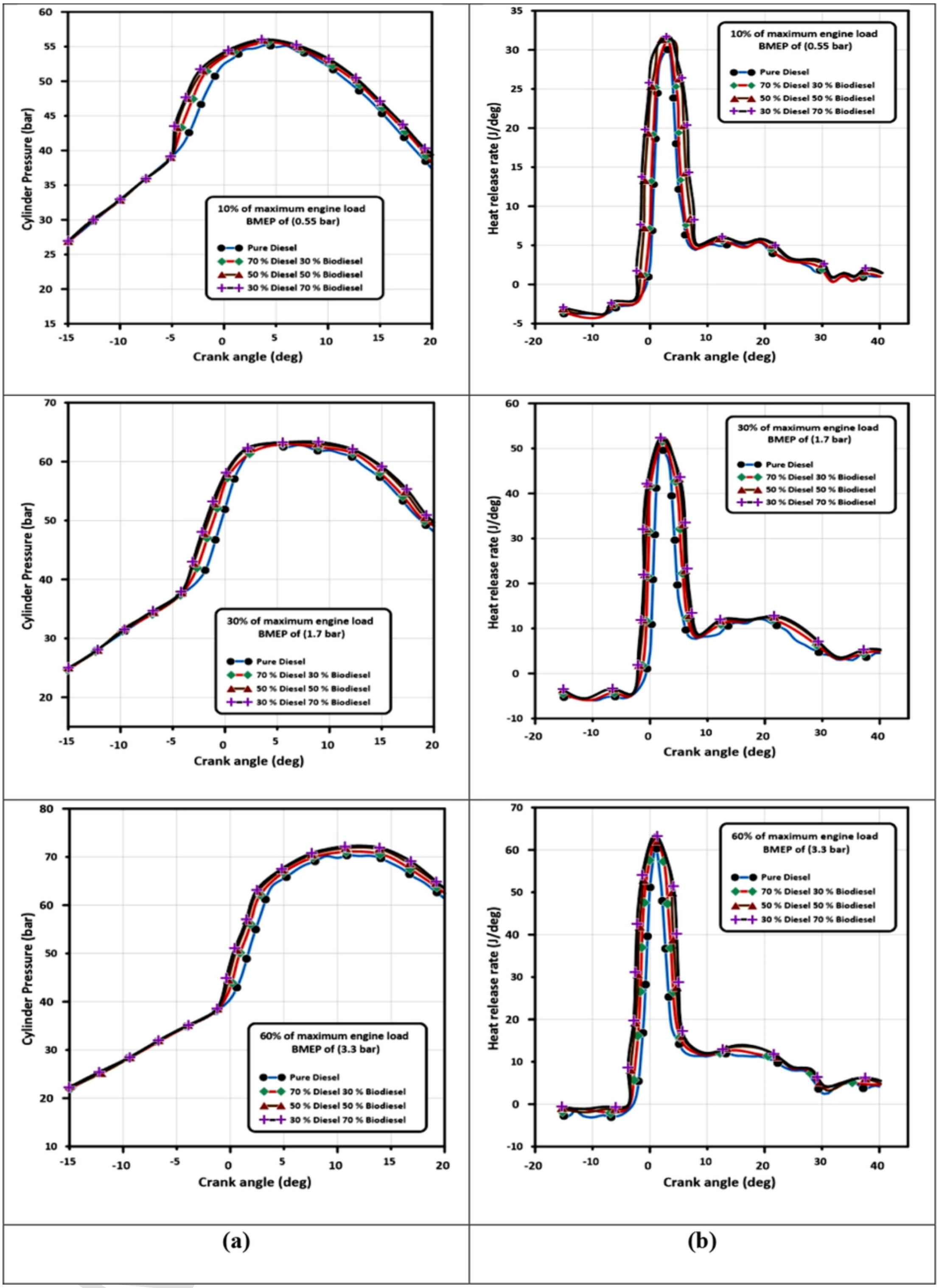

Fig. 9. Influence of different volumetric percentage of diesel/biodiesel blends of D70B30, D50B50 and D30B70 on combustion characteristics at three engine loads; a) In-cylinder pressure; b) Heat release rate.

measure different engine locations temperatures, where an air flow meter is used to quantify airflow rate. Emission values for the tested fuels were measured at a constant engine speed of 1400 rpm at different engine loads. Readings were recorded for two times, and an average value was taken to ensure measurements accuracy. Percentage of uncertainties of measured and calculated parameters are shown in Table 6.

The engine was allowed to run for sufficient time to make sure that the steady state operation has achieved. Therefore, in each experiment for a new fuel combination, the engine has operated for about thirty minutes by pure commercial diesel fuel to empty the engine fuel sys-

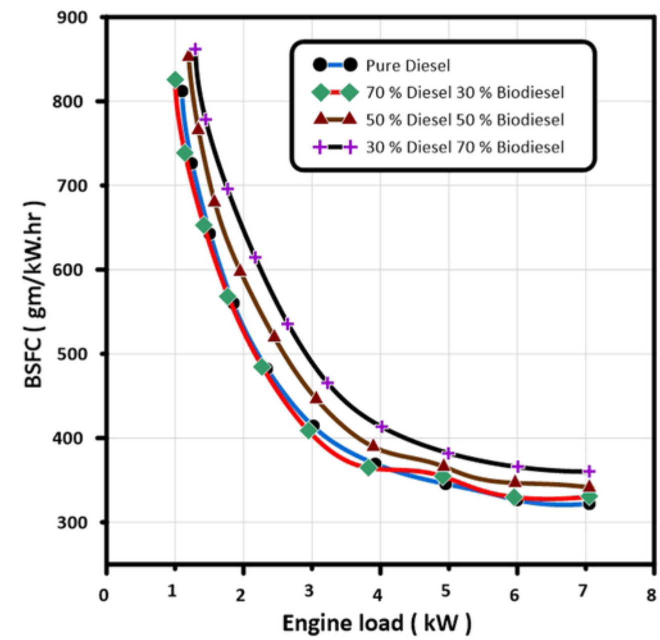

Fig. 10. Variation of BSFC with different engine loads for different tested fuels.

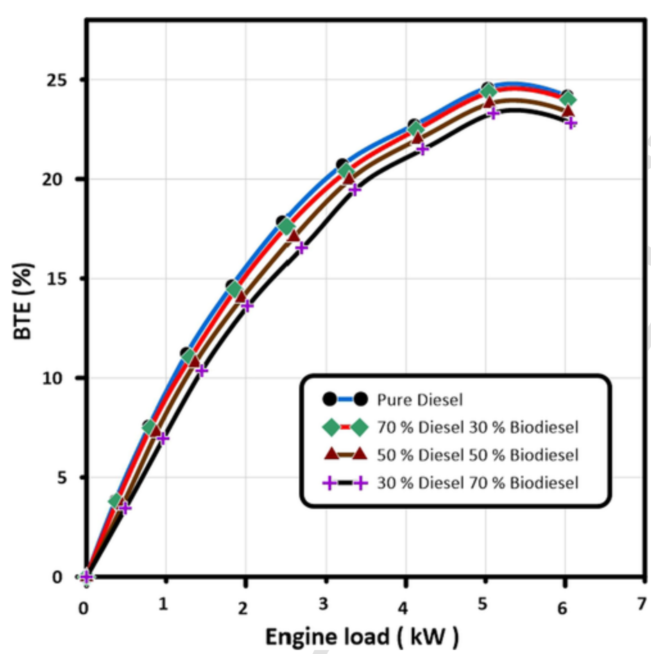

Fig. 11. Variation of BTE with different engine loads for different test fuels.

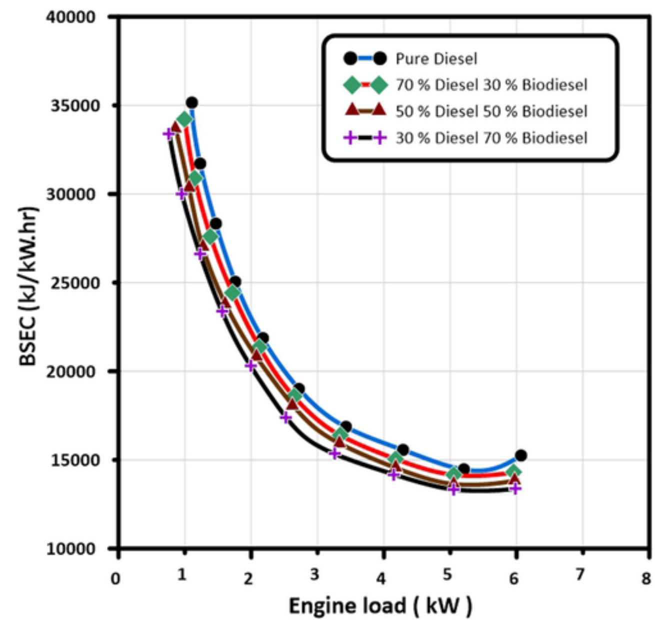

Fig. 12. Variation of BSEC with different engine loads for different test fuels.

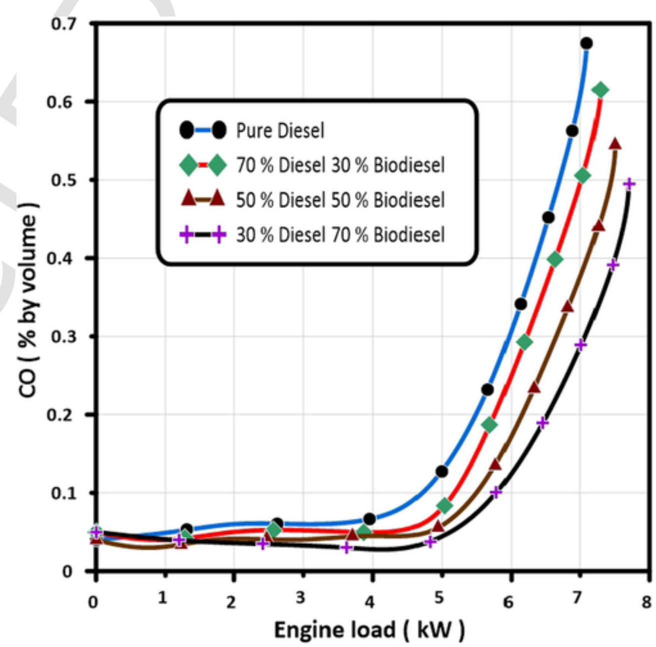

Fig. 13. Variation of CO emissions with different engine load for different test fuels.

tem from any remaining fuel from the previous experiment before running the engine on a new fuel.

3. Results and discussion

Transesterification parameters have a significant effect on biodiesel yield. The type of fuel used will affects performance and exhaust emissions of DI diesel engine. Therefore, this research focuses on the study and optimizes reaction parameters to find the optimal conditions to maximize the biodiesel yield. Also, investigate the effect of different biodiesel blends on engine performance and emissions characteristics.

3.1. Effect of transesterification parameters on biodiesel yield

3.1.1. Effect of methanol/oil ratio and catalyst loading on biodiesel yield

Methanol to oil ratio is one of the most critical parameters that affect biodiesel yield. The extra amount of methanol is usually used to shift reaction equilibrium in the product side, methyl ester. It is due to the reversible nature of the transesterification reaction. However, the optimum ratio depends upon the type of vegetable oil used and the quality of the oil. It has observed that by increasing the volumetric percentage of methanol, the yield increased until it reaches its optimum value. Any further increase will result in decreasing the yield, as shown in Fig. 3. This reduction may be due to that the excess amount of methanol would increase the solubility of glycerol, which arises a separation problem between methyl ester and its by-products. Therefore,

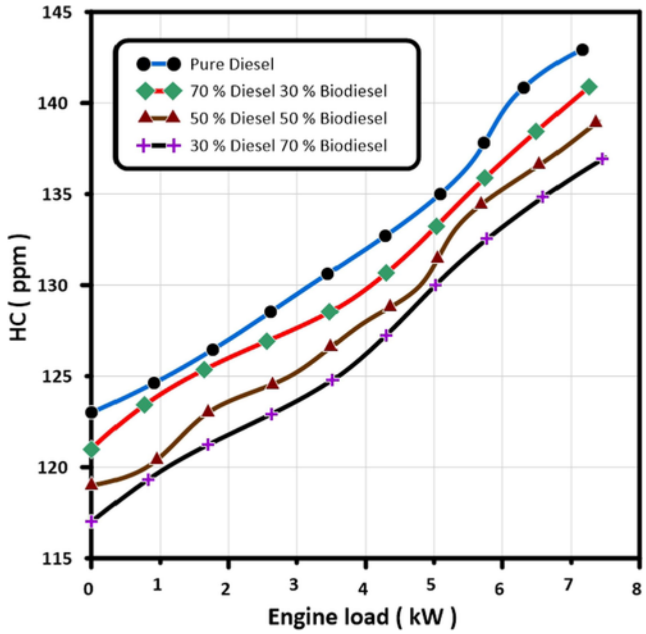

Fig. 14. Variation of HC emissions with different engine loads for different test fuels.

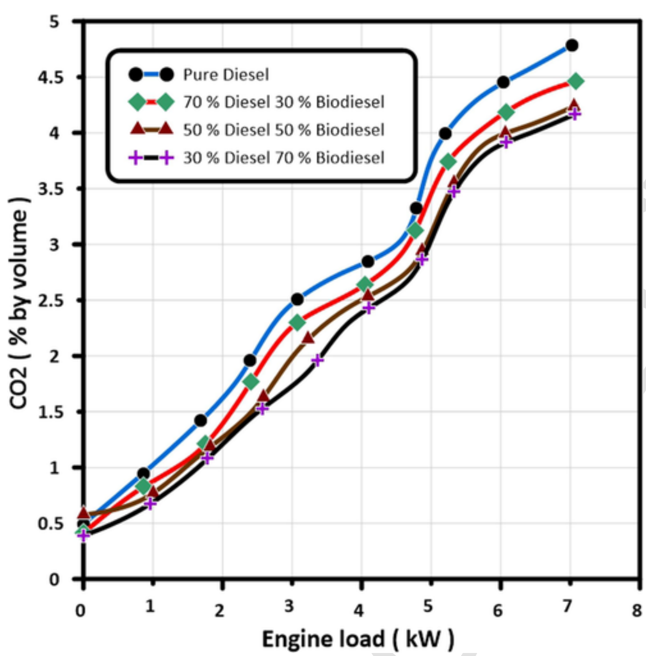

Fig. 15. Variation of CO2 emissions with different engine loads for different test fuels.

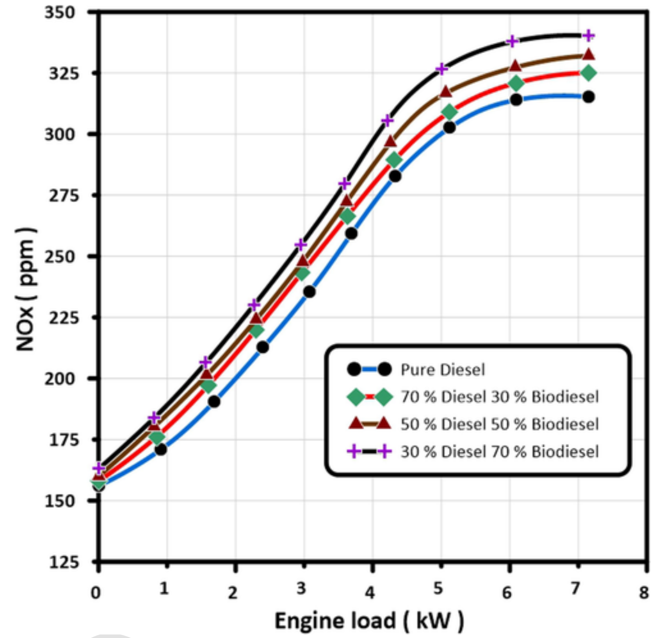

Fig. 16. Variation of NOx emissions with different engine loads for different test fuels.

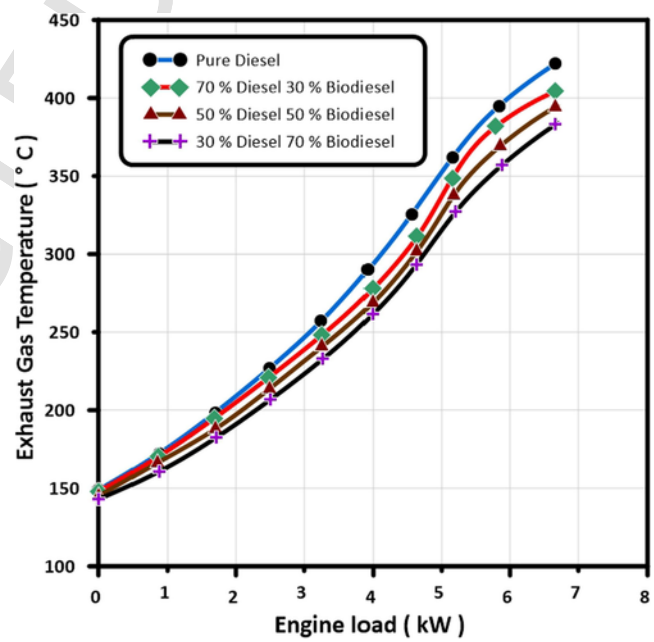

Fig. 17. Variation of EGT with different engine loads for different test fuels.

methyl ester is lost as part of dilute glycerol is stick on the ester phase. Also, excess methanol will lead to driving biodiesel and glycerol combination into mono-glycerides.

Catalyst concentration plays an essential rule in control the reaction rate of transesterification and affects both biodiesel yield and its characteristics. The obtained result shows that yield was low at a low amount of catalyst, as the reaction does not complete at a lower amount of NaOH. Yield increased with an increasing weight percentage of catalyst until it reaches its peak value. However, any further increase will result in decreasing the yield. Hydrolysis and saponification which caused by excess catalyst will lead to reducing biodiesel yield. Formation of soap prevents the separation of biodiesel phase in the washing step, as soap and water combination form emulsion which increase viscosity and form gels. The optimum methanol/oil ratio was between 19:1 and 21:1 V/V % for all catalyst loading conditions and the optimum catalyst concentration was about 0.6 wt%. Both optimum values give a maximum yield of approximately 93.5%.

3.1.2. Effect of methanol/oil ratio and mixing speed on biodiesel yield

Biodiesel yield increased as the amount of methanol increased until it reaches its optimum value, then decreased with a further increase of methanol percentage for all speeds tested, as shown in Fig. 4. Mixing intensity has a significant effect on the reaction, especially at the beginning, as reactants form two layers due to that oil is immiscible with methoxide solution. The obtained results show that yield was low at low mixing rate due to insufficient mixing between reactants. However, methyl ester yield increased with increasing mixing speed until reaching its peak value. High mixing rate above optimum value will result in a decrease in the biodiesel yield. It may be due to that after re-

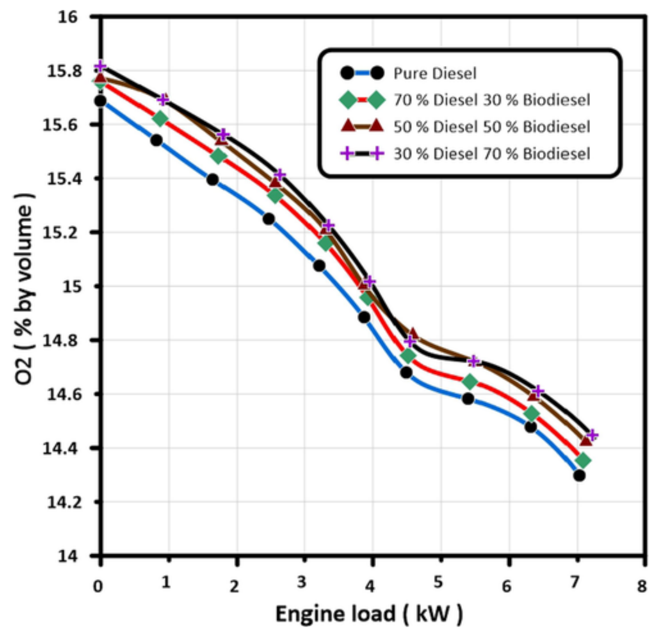

Fig. 18. Variation of Exhaust oxygen with different engine loads for different test fuels.

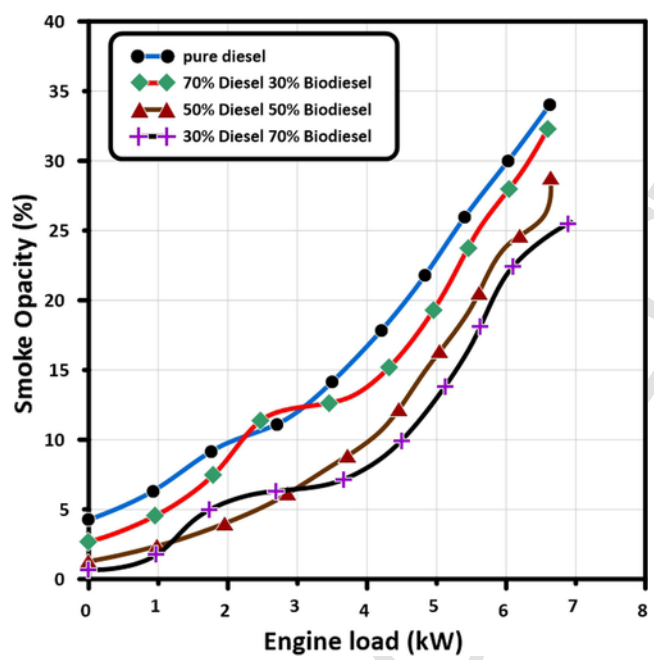

Fig. 19. Variation of Smoke Opacity with different engine loads for different test fuels.

actant depletion and product formation; the reverse reaction would dominate the reaction. The optimum value for methanol/oil ratio and mixing speed was about 19:1–21:1 V/V % at 500 rpm, respectively, which give a maximum biodiesel yield of 93.5%.

3.1.3. Effect of methanol/oil ratio and reaction time on biodiesel yield

Methanol/oil ratio effect does not change as discussed before, as biodiesel yield increased smoothly with increasing methanol ratio until it reaches its peak value then decreased with an excess amount of methanol above optimum value as shown in Fig. 5. Transesterification reaction converts triglyceride into biodiesel and glycerol in three steps, so reaction time must be optimized to ensure the completion of the response. Reaction time has a significant effect on methyl ester yield, as shown in Fig. 5. Results illustrate that yield increase directly with in-

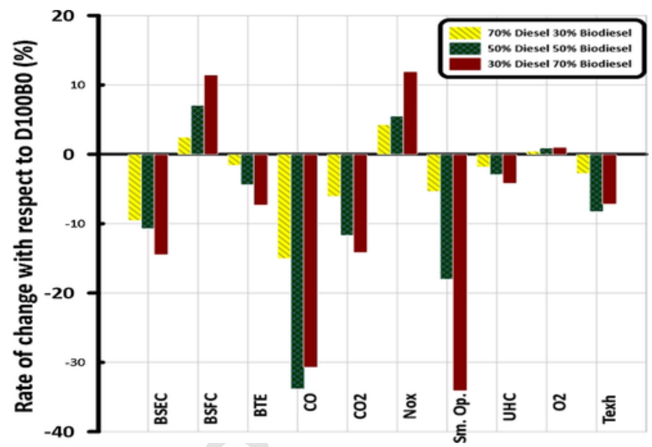

Fig. 20. Rate of change of the measured parameters with respect to D100B0 for different fuel blends.

creasing time, as the contact time between reactants increased. However, the yield fall over after reaching optimum value; this is may be due to more prolonged exposure of methanol and catalyst, which result in reverse reaction to take place. Fig. 5 shows that the optimum ratio of methanol and oil was about 19:1–21:1 V/V% for all reaction time experimented of 60 min was an optimum value. The maximum yield of 93.5% was reached with these optimum values.

3.1.4. Effect of mixing speed and catalyst loading on biodiesel yield

The elucidated results in Fig. 6 show that yield increased as mixing speed increased for all catalyst percentage tested as the optimum value range was from 475 to 525 rpm. It was observed that increasing the amount of catalyst increases the yield to an optimal limit of 0.6 wt% then biodiesel yield fall over. Biodiesel yield of about 93.5% can be reached at the optimal value of the two variables (as can be seen in Fig. 6).

3.1.5. Effect of mixing speed and reaction time on biodiesel yield

Graph represented in Fig. 7 shows that methyl ester yield is affected by both mixing rate and reaction time. It was noticed that the optimal mixing rate range was between 475 and 525 rpm for all reaction times, where the biodiesel yield increased until it reaches its peak value at optimized mixing speed. However, yield decreased with increasing speed rate above its optimal value. Also, the effect of reaction time was similar to the effect of agitation speed. As the optimal value was 60 min, which gives about 93.5% at optimal variables conditions, as can be seen in Fig. 7.

3.1.6. Effect of reaction time and catalyst loading on biodiesel yield

The obtained results show that both reaction time and catalyst loading take a similar trend, as noted by the previous data. However, as biodiesel yield increased with increasing both catalyst percentage and time until they reached an optimal value, which was in a range of 50–60 min reaction time and 0.6 wt% catalyst loading that results in a maximum yield of 93.5%, as shown in Fig. 8. Furthermore, the ester yield decreased with increasing the value of both above their optimum benefit.

3.2. DI engine combustion analysis

To explore the authority of different volumetric percentage of diesel/biodiesel blends: D70B30 (70% diesel–30% biodiesel), D50B50 (50% diesel–50% biodiesel) and D30B70 (30% diesel–70% biodiesel) on combustion characteristics, one thousand successive cycles of the engine process were recorded and analyzed. The main value of the pressure data have evaluated and analyses at different fuel blends with

Table 7
Rate of change in the values of the weighted mean for the measured parameters for different fuel blends.

Weighted Mean	Measured and calculated parameters of diesel & fuel blends				Rate of change With Respect to D100		
	D100	B30	B50	B70	For B30	For B50	For B70
BSEC	17,078	15,446	15,245	14,606	−9.55	−10.73	−14.47
BSFC	371	380	397	413	2.44	7.1	11.43
BTE	20.9	20.6	20.0	19.4	−1.59	−4.39	−7.32
Co	0.28	0.24	0.19	0.20	−15.02	−33.81	−30.73
CO2	3.6	3.4	3.2	3.1	−6.06	−11.68	−14.17
Nox	281	293	297	315	4.28	5.52	11.9
Smoke Op.	23	22	19	15	−5.4	−18.02	−34.09
UHC	136.6	134.1	132.5	131	−1.83	−2.94	−4.18
O2	14.6	14.7	14.8	14.8	0.45	0.89	0.98
T_{exh}	339	330	311	315	−2.77	−8.28	−7.17

varying engine loads. The obtained data represent the diagrams of the combustion pressure and heat release rate (HRR) of the engine, operated with baseline pure diesel fuel at and by different diesel/biodiesel blends. However, the combustion characteristics variables that describe the transformation reaction of the chemical energy in the fuel into heat energy such as pressure and heat release rate were analyzed as the previous researches activity [21,27].

3.2.1. Cylinder pressure analysis

Cylinder pressure is one of the most important variables in combustion characteristics analysis. It indicates the fuel burning efficiency and air to fuel mixture capacity during combustion phases. Fig. 9(a) shows the cylinder pressure variation for diesel and biodiesel blends at three different loads. All tested fuels show a similar trend for various loads, which is the common combustion pattern in diesel engine. At all loads, there was a convergence in maximum cylinder pressure for all tested fuels. Maximum cylinder pressure was 55.1, 63.3, and 72.2 bar for 10%, 30% and 60% of maximum engine power, respectively. Higher calorific value and self-ignition characteristics of diesel fuel give a maximum cylinder pressure during combustion process. Start of combustion (SOC) for biodiesel blends is earlier than diesel fuel due to higher Cetane number of biodiesel and higher oxygen content. The slight decrease in maximum cylinder pressure for higher percentage of biodiesel blends might be due to low calorific value of biodiesel and lower ignition delay.

3.2.2. Heat release rate (HRR)

Heat release rate depict the rate of chemical energy in the fuel to be converted into heat energy. Also, it describes the combustion phases during combustion process. Fig. 9(b) indicates the variation in HRR with respect to crank angle for all tested fuels at three different loads. HRR shows an identical trend for all tested fuels at different engine loading conditions. Results indicate that there was unnoticeable decrease in HRR for biodiesel blends as compared to diesel fuel. HRR was about 31.7, 52.4 and 63.5 (J/deg) for 10%, 30% and 60% of maximum engine power, respectively. Biodiesel blends show in the late combustion phase an accelerating in combustion than diesel fuel due to higher oxygen content in biodiesel. Obtained values indicated the fast combustion of biodiesel blends than diesel fuel and the ignition of fuels that have higher concentration of biodiesel was progressive as compared to diesel.

3.3. DI engine performance analysis

3.3.1. Brake specific fuel consumption (BSFC)

Variation in BSFC with engine load for tested diesel and biodiesel blends are shown in Fig. 10. Relationship between fuel properties and the spray characteristics during the combustion process has a significant effect on engine BSFC. Fig. 10 shows that BSFC decreases with increasing the engine load for all tested fuels, as by increasing engine power, it became more effective than the increasing rate of fuel consumption. It was found that BSFC increased with increasing the amount of diesel/biodiesel blends at different engine loads. The results showed an average increase in BSFC by 2.44%, 7.1%, 11.43% for D70B30, D50B50 and D30B70 blends, respectively than pure diesel. BSFC increment for biodiesel blends is due to the lower calorific value of biodiesel, so a more significant amount of fuel is required to produce the same power.

3.3.2. Brake thermal efficiency (BTE)

BTE of diesel engine shows the conversion efficiency of fuel chemical energy into actual useful work. As shown in Fig. 11, the BTE increases as engine load increases, because of the elucidated reduction on the values of BSFC. Therefore, the BTE for biodiesel blends was found to be lower than pure diesel fuel. The average value of the BTE was decreasing about 1.59%, 4.39%, 7.32% for D70B30, D50B50 and D30B70 blends than pure commercial diesel fuel, respectively. It may be due to higher viscosity, density, and surface tension of biodiesel than commercial diesel fuel. That will leads to both poor atomization and mixture formation with air, which produces slow combustion and low BTE.

3.3.3. Brake specific energy consumption (BSEC)

BSEC is a critical parameter as it describes the energy provided by the fuel to develop a unit engine power. In this work, there are different tested fuels with varying values of heating so BSEC would give an additional meaning about fuel consumption and efficiency of converting fuel energy into useful engine power. Results elucidated in Fig. 12 show that BSEC decreases with increasing biodiesel blending percentage for all load conditions of the engine. The average percentage decrease was about 9.55%, 10.73% and 14.47% for biodiesel blends of D70B30, D50B50 and D30B70, respectively, as compared to pure diesel fuel.

3.4. Engine exhausts emission analysis

3.4.1. Carbon monoxide (CO)

The CO emissions from the engine fueled by pure diesel and diesel/biodiesel blends are shown in Fig. 13. It was observed that by increasing the engine load, the CO emissions concentration was increased for all tested fuels. At higher load, there was a significant increase in CO emissions that was due to the rich mixture needed, which leads to incomplete combustion. There was an average decrease in CO emissions levels for biodiesel blends than diesel fuels, about 15.02%, 33.81%, and 30.73% for D70B30, D50B50 and D30B70, respectively. It was mainly due to higher oxygen content and low carbon to hydrogen ratio that helps incomplete combustion of biodiesel blends inside the engine cylinder.

3.4.2. Hydrocarbons emissions (HC)

HC emissions are one of the essential parameters in emission analysis. Incomplete combustion is the main reason for hydrocarbons emissions. It is clear from Fig. 14 that, HC emissions are found to be lower at both no load and partial load conditions than at higher engine loads. This is due to less oxygen available for completing the combustion reaction when more fuel is injected at higher loads conditions. However, HC emissions decreased with increasing the ratio of biodiesel in the mixture of diesel/biodiesel blends due to the higher oxygen content in biodiesel than diesel fuel, which leads to clean and complete combustion. Hence, biodiesel blends of D70B30, D50B50 and D30B70 produce an average decrease of 1.83%, 2.94%, 4.18%, respectively, than pure diesel.

3.4.3. Carbon dioxide (CO2)

CO2 emissions variation have been observed at different engine loads for different tested fuels as can be seen in Fig. 15. CO2 emissions for pure diesel and diesel/biodiesel blends increased over entire measured loads of operation. CO2 emissions show an average decrease by 6.06%, 11.68%, and 14.17% for diesel/biodiesel blends of D70B30, D50B50 and D30B70, respectively, as compared with pure diesel. This reduction may be due to incomplete combustion, especially at higher engine loads, also low C/H ratio may be another reason. However, this reduction shows a positive impact on reducing greenhouse gas emissions.

3.4.4. Nitrogen oxide (NOx)

The NOx emissions inconstancy to different engine load is shown in Fig. 16. The NOx emissions are determined by equivalence ratio, oxygen concentration, and combustion temperature and combustion residence time. NOx formation during the uncontrolled combustion phase is produced where higher temperature regions are appearing. Therefore, it has been observed that NOx increases with increasing the engine load for all tested fuels, due to higher combustion temperature. Biodiesel blends produce higher NOx emissions than pure diesel fuel at all load conditions due to the existence of more oxygen content in biodiesel fuels, which leads to higher NOx formation. A calculated average increase was found to be 4.28%, 5.52%, 11.9%, for diesel/biodiesel blend of D70B30, D50B50 and D30B70, respectively. NOx is one of the most harmful emissions produced from the engine that can be reduced by a different method such as exhaust gas recirculation (EGR) and reducing the in-cylinder temperature by lean burn combustion strategy.

3.4.5. Exhaust gas temperature (EGT)

The variation in EGT for different engine loads for different tested fuels is shown in Fig. 17. It is clear from the obtained results that, EGT increases as engine load increases for all tested fuels. For all biodiesel blends, the maximum EGT is lower than diesel fuels. It was also observed that EGT was reduced by increasing the biodiesel percentage in the fuel. However, ignition delay has a significant effect on EGT variation. Higher EGT and delayed combustion result from longer ignition delay. Biodiesel has a higher Cetane number (CN), which result in lower ignition delay, which is the main reason for lowering EGT, but the engine exhibits higher coolant and oil temperature. About 2.77%, 8.28%, 7.17%, is found to be an average reduction of EGT for diesel/biodiesel blends of D70B30, D50B50 and D30B70, respectively.

3.4.6. Exhaust oxygen (EO)

Fig. 18 shows EO variation with varying loads of engine for the tested fuels. EO concentration levels point to oxygen percentage in the sample and the transition from rich to lean mixture. The figure indicates that EO decreases with increasing engine load for all examined fuels. Also, EO for all biodiesel blends was found to be higher than pure diesel, whereby increasing the biodiesel substitution in diesel, the EO expands. This is may be due to incomplete combustion, exhaust system or manifold leakage. A small average increase was observed to be 0.45%, 0.89%, 0.98% for biodiesel blends of D70B30, D50B50 and D30B70, respectively.

3.4.7. Smoke opacity

Fig. 19 shows smoke opacity variation with respect to diesel and biodiesel blends. It has been noticed that the smoke increases with increasing load until it reaches its highest value at high load condition. Incomplete combustion occurs at high loads due to that more fuel is injected, which leads to high smoke levels. It was observed a reduction in smoke with increasing biodiesel percentage in the tested blended fuel at all load conditions. Biodiesel based fuels have more oxygen content and less carbon as compared to diesel fuel, which explains the reduction in smoke. Biodiesel as an oxygenated fuel improves the diffusive combustion phase where smoke is mainly produced. Also, oxygen presence in biodiesel fuel has a significant effect on the oxidation of carbon residual, which decreases smoke level. An average reduction in smoke was about 5.4%, 18.02%, 34.09% for diesel/biodiesel ratios of D70B30, D50B50, and D30B70, respectively as compared to diesel fuel.

3.5. Rate of change of engine parameters and gas emissions with respect to pure diesel:

Fig. 20 shows the rate of decrease and increase of measured engine performance and emissions parameters and with respect to pure commercial diesel fuel D100 for three tested different blends of D70B30, D50B50, and D30B70. Table 7 shows the calculated values of the rate of change and the weighted mean of the measured and calculated parameters of diesel and fuel blends that calculated as the following equation:

The weighted mean of the measured parameters = $\frac{(x1*y1)+(x2*y2)+......(xn*yn)}{x1+x2+.........+xn}$ where x1, represent the measured engine load, while y1 is the corresponding values of the measured parameters. However, the rate of increase and decrease to D100 is calculated as the following equation:

The change rate of different blends concerning D100B0 = $\frac{DXBY-D_{100}B_0}{D_{100}B_0}$ where X and Y represent the concentration of diesel and biodiesel, respectively.

4. Conclusions

The main conclusion points could be summarized, as shown below:

- Optimum conditions for reaction parameters were within the range of 19:1–21:1 V/V % methanol/oil ratio, 0.6 wt% catalyst loading, 50–60 min reaction time and 475–525 rpm mixing speed.
- The maximum value of Biodiesel yield was about 93.5% at optimal reaction conditions.
- Biodiesel volumetric percentage of 30%, 50% and 70% showed a reduction in CO, HC and CO_2 emissions about 2.54–10.15%, 1.83–4.18% and 6.06–14.17%, respectively, as compared to diesel fuel.
- NOx emissions had an average increase of 4.28–11.9% that was observed for biodiesel blends with respect to pure diesel.
- EO emissions showed a slight increase of about 0.45–0.98% for biodiesel ratios of 30%, 50%, and 70%.
- EGT was reduced by 2.77–7.17% with increasing biodiesel percentage.
- BSFC increased by about 2.44–11.43%, where BTE had an average reduction of about 1.59–7.32% for tested blends in comparison with diesel fuel.
- Biodiesel percentage of 30%, 50%, and 70% in blended fuel showed a reduction in BSEC about 5.67%, 4.38%, and 1.15%, respectively.

- An average reduction in smoke was about 4.7%, 2.86%, and 0.51% for diesel/biodiesel blends of D70B30, D50B50, and D30B70, respectively.
- Biodiesel produced from sunflower and soybean oil mixture could be blended with diesel up to 70%, which play a vital role as an alternative fuel solution for powering diesel engines without any modifications.
- The slight decrease in maximum cylinder pressure for higher percentage of biodiesel blends might be due to low calorific value of biodiesel and lower ignition delay.
- Results indicate that there was unnoticeable decrease in HRR for biodiesel blends as compared to diesel fuel. HRR was about 31.7, 52.4 and 63.5 (J/deg) for 10%, 30% and 60% of maximum engine power.

References

[1] E.A. Shenawy, Medhat Elkelawy, Hagar Alm-Eldin Bastawissi, Hitesh Panchal, Comparative study of the combustion, performance, and emission characteristics of a direct injection diesel engine with a partially premixed lean charge compression ignition diesel engines, Fuel 249 (2019) 277–285.

[2] Hagar Alm El DinBastawissi, Medhat Elkelawy, Hitesh Panchal, Kishor Kumar Sadasivuni, Optimization of the multi-carburant dose as an energy source for the application of the HCCI engine, Fuel 253 (2019) 15–24.

[3] S. Chandra Sekhar, et al., Biodiesel production process optimization from Pithecellobium dulce seed oil: performance, combustion, and emission analysis on compression ignition engine fuelled with diesel/biodiesel blends, Energy Convers Manage 161 (2018) 141–154.

[4] M. Anwar, M.G. Rasul, N. Ashwath, Production optimization and quality assessment of papaya (Carica papaya) biodiesel with response surface methodology, Energy Convers Manage 156 (2018) 103–112.

[5] U. Rashid, F. Anwar, B.R. Moser, Ashraf SJB and bioenergy, Production of sunflower oil methyl esters by optimized alkali-catalyzed methanolysis, Biomass Bioenergy 32 (12) (2008) 1202–1205.

[6] X. Meng, G. Chen, Y. Wang, Biodiesel production from waste cooking oil via alkali catalyst and its engine test, Fuel Process Technol 89 (9) (2008) 851–857.

[7] A.N. Phan, T.M. Phan, Biodiesel production from waste cooking oils, Fuel 87 (18–17) (2008) 3490–3496.

[8] S. Keera, S. El Sabagh, A.R. Taman, Castor oil biodiesel production and optimization, Egpt J Petrol 27 (4) (2018) 979–984.

[9] A.S. Nejad, A.R. Zahedi, Optimization of biodiesel production as a clean fuel for thermal power plants using renewable energy source, Renew Energy 119 (2018) 365–374.

[10] D.O. Onukwuli, L.N. Emembolu, C.N. Ude, S.O. Aliozo, M.C. Menkiti, Optimization of biodiesel production from refined cotton seed oil and its characterization, Egpt J Petrol 26 (1) (2017) 103–110.

[11] C.B. Ezekannagha, C.N. Ude, O.D. Onukwuli, Optimization of the methanolysis of lard oil in the production of biodiesel with response surface methodology, Egpt J Petrol 26 (4) (2017) 1001–1011.

[12] G.A. Miraculas, N. Bose, R.E. Raj, Process parameter optimization for biodiesel production from mixed feedstock using empirical model, Sustain Energy Technol Assess 28 (2018) 54–59.

[13] L. da Costa Cardoso, F.N.C. de Almeida, G.K. Souza, I.Y. Asanome, N.C. Pereira, Synthesis and optimization of ethyl esters from fish oil waste for biodiesel production, Renew Energy 133 (2019) 743–748.

[14] K.T. Kucek, M.A.F. César-Oliveira, H.M. Wilhelm, L.P. Ramos, Ethanolysis of refined soybean oil assisted by sodium and potassium hydroxides, J Am Oil Chemists Soc 84 (4) (2007) 385–392.

[15] J. Encinar, J. González, A.R. Rodríguez-Reinares, Ethanolysis of used frying oil. Biodiesel preparation and characterization, Fuel Process Technol 88 (5) (2007) 513–522.

[16] S.C. Sekhar, et al., Biodiesel production process optimization from Pithecellobium dulce seed oil: performance, combustion, and emission analysis on compression ignition engine fuelled with diesel/biodiesel blends, Energy Convers Manage 161 (2018) 141–154.

[17] A. Saydut, S. Erdogan, A.B. Kafadar, C. Kaya, F. Aydin, C.J.F. Hamamci, Process optimization for production of biodiesel from hazelnut oil, sunflower oil and their hybrid feedstock, Fuel 183 (2016) 512–517.

[18] Elkelawy M, et al., Numerical and Experimental Investigation of Ethyl Alcohol as Oxygenator on the Combustion, Performance, and Emission Characteristics of Diesel/Cotton Seed Oil Blends in Homogenous Charge Compression Ignition Engine, 2018. doi: 10.4271/2018-01-1680

[19] B.S. Chauhan, N. Kumar, H.M. Cho, H.C. Lim, A study on the performance and emission of a diesel engine fueled with Karanja biodiesel and its blends, Energy 56 (2013) 1–7.

[20] S.C. Sekhar, et al., Emission analysis on compression ignition engine fueled with lower concentrations of Pithecellobium dulce biodiesel-diesel blends, Heat Trans Asian Res 48 (1) (2019) 254–269.

[21] Ö. Can, Combustion characteristics, performance and exhaust emissions of a diesel engine fueled with a waste cooking oil biodiesel mixture, Energy Convers Manage 87 (2014) 676–686.

[22] S. Lahane, K.J.F. Subramanian, Effect of different percentages of biodiesel-diesel blends on injection, spray, combustion, performance, and emission characteristics of a diesel engine, Fuel 139 (2015) 537–545.

[23] C. Cheung, X. Man, K. Fong, O.K. Tsang, Effect of waste cooking oil biodiesel on the emissions of a diesel engine, Energy Procedia 66 (2015) 93–96.

[24] K. Abed, A. El Morsi, M. Sayed, A. El Shaib, M.S. Gad, Effect of waste cooking-oil biodiesel on performance and exhaust emissions of a diesel engine, Egpt J Petrol 27 (4) (2018) 985–989.

[25] O. Özener, L. Yüksek, A.T. Ergenç, M.J.F. Özkan, Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics, Fuel 115 (2014) 875–883.

[26] L.A. Raman, B. Deepanraj, S. Rajakumar, V.J.F. Sivasubramanian, Experimental investigation on performance, combustion and emission analysis of a direct injection diesel engine fuelled with rapeseed oil biodiesel, Fuel 246 (2019) 69–74.

[27] Ö. Can, E. Öztürk, H. Serder Yücesu, Combustion and exhaust emissions of canola biodiesel blends in a single cylinder DI diesel engine, Renew Energy 109 (2017) 73–82.