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Production of biodiesel from various sources and comparative engine performance studies by using different biodiesel blends

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ABSTRACT

The biodiesel production from *Pongamia pinnata, Calophyllum inophyllum,* and waste cooking oil with different free fatty acid content was carried out by using different stages of transesterification process. Physical and chemical properties of biodiesel such as flash point, fire point, calorific value, density, and viscosity were found. Engine performance studies were carried out, with 100 % biodiesel being produced from different sources and with blends such as B50, B65, and B80 with diesel. In the comparison of biodiesels, it was found that *Pongamia pinnata* biodiesel showed highest Brake Thermal Efficiency (BTE) among the biodiesels used. For the B65 blend, Pongamia pinnata biodiesel gives highest BTE. For B50 blend, *Pongamia pinnata* and *Calophyllum inophyllum* biodiesel provide highest BTE. When these blends were compared for a particular type of biodiesel, B50 shows better performance characteristics in all aspects for different biodiesels used and among the biodiesel blends used.

Keywords: Biodiesel production; *Pongamia pinnata; Calophyllum inophyllum*; waste cooking oil; brake thermal efficiency.

INTRODUCTION

During the past few decades, there has been an increased interest in searching for alternative energy sources in the transportation and energy sectors. The goal is to depreciate the fossil fuel want, a craving to reduce greenhouse emissions (specially CO_2 in the transportation sector) and human health connected to pollutant emissions (HC, NO_x,CO, smoke, etc.). Research reveals that unregulated emissions at present rate will lead to 41% increase in emissions by 2030. Because of this, new laws are being introduced to support the use of biofuels in the transportation sector, and strict pollutant emission regulations must be fulfilled, thus demanding the incorporation of after-treatment systems. Efforts to tackle these challenges have been based on both engine and fuel-focused techniques. The focus now lies on biofuels obtained from sources that are not fit for human consumption. Fast reduction of petroleum fuels and their ever-growing prices have led to a rigorous pursuit of substitute fuel, produced from local, non-conventional resources. Even though biodiesel does not have compatible petroleum properties, it can be used in the existing diesel engines without modification by blending it at any level with petroleum diesel. There are many sources from which biodiesel can be produced. *Calophyllum inophyllum,* waste cooking oil, and *Pongamia pinnata* are the sources from which biodiesel can be produced by a process called transesterification.

Transesterification is a chemical method from which biodiesel is prepared, in which the glycerin is parted from the fat or vegetable oil. The transesterification is accomplished with monohydric alcohols like methanol and ethanol alongside with NaOH catalyst. Hence the biodiesel produced from this process is methyl ester. Biodiesel blends with petroleum-centered diesel fuel can be used in diesel engines without any noteworthy alterations to the engines. The use of biodiesel in CI engine fuel may diminish environmental pollution, support agricultural economy, generate employment prospects, decrease diesel fuel necessities, and thus help in conserving a main commercial energy source.

BACKGROUND

Avinash *et al.* (2012) manufactured biodiesel from *Calophyllum inophyllum* kernel oil by a transesterification process. The physical properties of this biodiesel were tested. Engine performance studies were conducted by using blends along with an additive called SC5D. The blends prepared were B10, B20, B30, and B40 along with pure biodiesel. The additive in biodiesel increased brake thermal efficiency and decreased fuel consumption. There was a rise in NOx and exhaust gas temperature along with increment in the biodiesel in the blend. Ashrafur *et al.* (2013) manufactured biodiesel from *Calophyllum inophyllum* and palm oil and conducted engine performance studies specifically for low load situations. Engine tests were conducted at 1000 rpm, 1200 rpm, and 1500 rpm for low load conditions of 10%, 12%, and 15% loading, respectively, along with the blends of *Calophyllum inophyllum* and palm biodiesel for B5, B10, and B20. The brake specific fuel consumption (BSFC) was lower in case of diesel than in the case of *Calophyllum inophyllum* and palm oil. The BSFC was lower in case of *Calophyllum inophyllum* when compared with palm biodiesel due lower calorific value of palm biodiesel. At 1500 rpm, the rise in BSFC was lower due to higher temperature and intrinsic oxygen present. The brake thermal efficiency (BTE) is better in the case of *Calophyllum inophyllum* biodiesel compared to palm biodiesel. Palm biodiesel emitted higher emissions than *Calophyllum inophyllum* biodiesel due to higher viscosity causing incomplete combustion. At higher speed NOx emission was lower, due to shorter ignition delay period. Hwang *et al.*)2013(performed biodiesel experiment by using waste cooking oil. The engine performance was conducted at different loads and different injection pressures. The biodiesel combustion took place later than diesel due to lengthier injection delay of biodiesel, as the viscosity of biodiesel is greater than that of diesel, thus triggering longer delays. There is friction in the nozzle because of higher viscosity. Peak cylinder pressure rate of biodiesel was noted to be lower than the diesel; the reason for this is the lower combustion rate of biodiesel because of higher viscosity, causing lower mixing of air and lower calorific value, thus resulting in lesser heat release rate for biodiesel. Kulkarni *et al.* (2008) produced biodiesel from acid oil obtained from vegetable oil refineries, which is one of the by-products of these oil refineries. Acid oil contains very high free fatty acid (FFA) value of 87%. Acid oil has been converted into biodiesel by using an esterification process, which gave a yield of about 70 to 80 % biodiesel. Biodiesel properties differed with different sources, and various physical and chemical properties of biodiesel were tested. Kumar *et al.* (2008) produced biodiesel from *Pongamia pinnata* and tested the properties using different blends of biodiesel, and engine test was conducted. BSFC showed a decrease with increasing the load. CO concentration was almost absent for blends up to B60 because of lesser biodiesel oxygen in it, which helped in complete combustion. CO_2 was lower in B40 as the biodiesel had lower carbon content and because of complete combustion of fuel. With increasing biodiesel percentage CO increased because of higher viscosity, and HC was lower, except in B20 blend. Exhaust gas temperature (EGT) is an indication of efficient combustion, which was highest in diesel and showed a decreasing trend with increasing the biodiesel content. The B40 blend showed better characteristics for diesel fuel replacement. Cheng *et al.* (2007) produced biodiesel from diethylene glycol diethyl ether (DGE), which is a promising fuel additive for compression engines based on its high cetane number and its high amount of fuel burn oxygen. Bojan *et al.* (2012) took *Jatropha curcas* as the source for biodiesel. Lower yield of biodiesel was given by *Jatropha* with high free fatty acid content. The yield was improved by using a two-step transesterification process by 12.5% compared to the single-step process. Christensen *et al.* (2014) studied the stability of biodiesel and analyzed degradation of biodiesel by aging it over a period of time. The use of antioxidants delayed the degradation of biodiesel, but it also depended on the storage condition.

Motivation

The literature review indicates that major work has been carried out for a particular biodiesel and its blends with lower percentage of biodiesel. Hence, in the present work, biodiesel is produced from various sources so as to check which biodiesel is more suitable or more compatible with the existing diesel engine and to conduct performance test with 100% different biodiesels and their blends with higher percentage of biodiesel with diesel. In the present work, biodiesel produced from various sources, which are continuously available and not viable for human consumption, was used. Different stages of transesterification process for producing biodiesel depending on its free fatty acid content were employed. The physical and chemical fuel properties of these biodiesels were compared and evaluated. Engine performance of these biodiesels was performed and compared. Performance tests by blending it with diesel with higher percentage of diesel were conducted. The rest of the article is composed as follows: Section 2 provides the materials and methods adopted for production of biodiesel. In Section 3, the properties of the obtained biodiesel and infrared spectroscopy analysis are mentioned. Results are discussed in Section 4, and conclusions are reported in Section 5.

MATERIALS AND METHOD

In the present Section, materials used for the production of biodiesel from raw oils like Calophyllum inophyllum (CI), *Pongamia pinnata* (PP), and waste cooking oil (WC) are reported. Properties of these oils are tested and reported. Preparation of blends: B50, B65, B80, and B100 are briefly indicated. Properties of these blends have also been discussed. Infrared spectroscopy analysis carried out using bunkers spectrometer for B100 is also shown.

Properties of raw oils

Properties of *Calophyllum inophyllum, Pongamia pinnata*, and waste cooking are reported in Table 1.

Table 1. Properties of Calophyllum inophyllum, Pongamia pinnata, and waste cooking.

Properties	***Calophyllum inophyllum oil***	***Pongamia pinnata oil***	**Waste cooking oil**	**Diesel**
Flash point ºC	220	215	198	53
Fire point ºC	228	220	205	64
Calorific value kJ/kg	37254.36	30400	35007.29	42500
Kinematic viscosity (cSt)	48	39	6	3.45

The values of flash point, fire point, and kinematic viscosity are very high as seen in Table 1. With these high values, oils cannot be used directly in diesel engine as it leads to clogging.

Production of biodiesel

Free fatty acid (FFA) content test was *performed for Pongamia pinnata, Calophyllum* inophyllum, and waste cooking oil using the below equation and further, the values obtained are mentioned in Table 2.

Table 2. FFA content of different crude oils.

Raw Oil	***Pongamia pinnata oil***	***Waste cooking oil***	***Calophyllum inophyllum oil***
FFA	4%	2%	29.61%

FFA Content = 28.2*(normality of NaOH)*(Titration value)/weight of oil

From Table 2, the FFA values obtained give us the type of transesterification process to be carried out, which will be either single-stage or double-stage process, and the amount of NaOH is to be added.

Production of biodiesel from waste cooking oil and *Pongamia pinnata* oil

One liter of oil is measured and transferred into a three-necked flask provided as part of the laboratory set. The three-necked flask is placed on a magnetic stirrer. 300ml methanol per liter of oil is mixed. The setup is maintained and controlled to 600° C temperature. 5.5 grams of NaOH for 2% FFA (waste cooking oil) and 6.5 grams of NaOH for 4% FFA (honge oil) determined earlier for the raw oil are added, and then methanol is added; this mixture is called “methoxide” mixture. When the temperature reaches 630° C, methoxide mixture is added slowly to the hot oil. Maintain the temp at 600C to 630C. Run the process for 30 min and observe the color of the mixture turning from turbid orange to transparent chilly red. After the first 30 min, a sample is drained and allowed to settle. Two distinct layers will be obtained, indicating the chemical reaction is proceeding in the right direction. The bottom layer is glycerine. The glycerine layer is drained from separating funnel from the bottom carefully and stored. The biodiesel is allowed to settle for another half an hour and was observed if there is any further glycerine content to settle.

Washing

Transfer biodiesel into washing funnel and spray 300 ml of warm water at 600C slowly into biodiesel without any agitation. Allow it to settle for 1 hour; a bottom layer of soap water will slowly start to foam. Drain the bottom layer carefully. Again spray 300ml of warm water and allow it to settle for 1 hour. Drain the bottom layer carefully. Repeat the procedure for a third time and shake vigorously and allow it to settle for one hour and drain soap water. Check up the pH value of the third soap water using pH paper provided as part of the lab kit. Continue the process with the warm water till the biodiesel reaches 7pH.

Production of biodiesel from *Calophyllum inophyllum* oil

1 liter of CI oil is added with 7.5 ml of concentrated H2SO4. FFA test is performed, which is found to be 9.3. Add 2.5 ml of concentrated H2SO4 and 300 ml of methanol and allow it to be stirred and heated at 600 C for 1 hour. Again perform the FFA test, and FFA is found to be 4%. Now add 7.5 gms of NaoH and 300 ml of methanol and allow it to be stirred and heated at 600 C for 1 hour. The obtained biodiesel is transferred to washing funnel.

Washing

Transfer biodiesel into washing funnel and spray 300 ml of warm water at 600C slowly into biodiesel without any agitation. Allow it to settle for 1 hour; a bottom layer of soap water will slowly start to foam. Drain the bottom layer carefully. Again spray 300ml of warm water and allow it to settle for 1 hour. Drain the bottom layer carefully. Repeat the procedure for a third time and shake vigorously and allow it to settle for one hour and drain soap water. Check up the pH value of the third soap water using pH paper provided as part of the lab kit. Continue the process with the warm water till the biodiesel reaches 7pH.

Drying

Biodiesel is transferred from “washing funnel” into the 1 liter beaker; magnetic pallet is added and RPM is adjusted to a suitable speed. Biodiesel is heated to a temp of 1000C (moisture evaporates). Biodiesel was allowed to cool gradually. It is stored in a clean, dry container.

Preparation of blends

Distilled biodiesels of required quantities are taken for blending. Two burettes are taken and cleaned with acetone to avoid contamination of fuels. For the first blend, 50ml of biodiesel and 50ml of diesel are taken in a 50:50 ratio to prepare blend B50. Similarly other blends of biodiesel are prepared for B65 and B80 for prepared biodiesels, that is, acid oil methyl ester, waste cooking oil methyl ester, *Pongamia pinnata* methyl ester, and *Calophyllum inophyllum* methyl ester. The blends are stirred for a period of five minutes using a magnetic and electric motor stirrer for homogeneity.

PROPERTIES OF BIODIESEL

After the production, the obtained biodiesel was tested for its properties. The changes in properties obtained after conversion of oil to biodiesel can be easily compared in Table 1 and Table 2. Kinematic viscosity, flash point, and fire point have decreased, whereas, on the other hand, the Calorific value has increased. These changes obtained in the properties after the transesterification process are now closer to diesel; hence we can use these biodiesels in our experiment in diesel engine.

Table 3. Properties of oil.

Properties	**unit**	***Pongamia pinnata methyl ester***	***Waste cooking oil methyl ester***	***Calophyllum inophyllum* methyl ester**	**Diesel**
Density	kg/m3	890	875	895	845
Flash point	°C	160	157	135	53
Fire point	° C	174	169	149	64
Cloud point	° C	12	12	13	-5
Pour point	° C	7	8	10	-16
Calorific value	kJ/kg	36387.22	41136.88	39112.626	42500
Kinematic viscosity at 40°c	cSt	9.42	3.9857	9.0869	3.45

We have blended the obtained biodiesel with diesel, and the blends prepared are B50, B65, and B80. The properties of the mentioned blends from the biodiesels prepared using *Pongamia pinnata, Calophyllum inophyllum*, and waste cooking oil are shown in Table 3. From this table the variation in the properties of the blends with the change in the percentage amount of biodiesel content can be illustrated. Density, kinematic viscosity, and flash and fire point have decreased with the decrease in the biodiesel content in all the blends, and there is an increase in the calorific value with a decrease in biodiesel content of the blends.

Table 4. Properties of different blends.

	Pongamia pinnata			*Calophyllum inophyllum*			Waste Cooking Oil		
Properties	B50: D50	B65: D35	B80: D20	B50: D50	B65: D35	B80: D20	B50: D50	B65: D35	B80: D20
Density Kg/m3	852	860	873	844	856	868	836	856	868
Calorific value kJ/kg	39443.6	38526.6	37609.8	40806.313	40298.20	39790.1	41818.44	41613.97	41409.5
Viscosity cSt	5.81	6.82	7.11	4.711	5.24	6.27	3.79	3.83	4.68
Flash point °C	58	74	86	60	72	90	62	78	92
Fire point °C	66	78	90	68	90	98	70	84	102

Infrared spectrum of biodiesel from *Calophyllum inophyllum,* waste cooking oil, and Pongamia pinnata

The infrared spectrum of the sample is recorded by passing a beam of infrared light through the sample. When the frequency of the IR is the same as the vibrational frequency of a bond, absorption occurs. Examination of the transmitted light reveals how much energy was absorbed at each frequency (or wavelength). IR spectroscopy is used to identify structures because functional groups give rise to characteristic bands both in terms of intensity and position (frequency). Our biodiesel samples were tested in BRUKER ALPHA FT-IR Spectrometer, and the analysis of the result is shown in the tables.

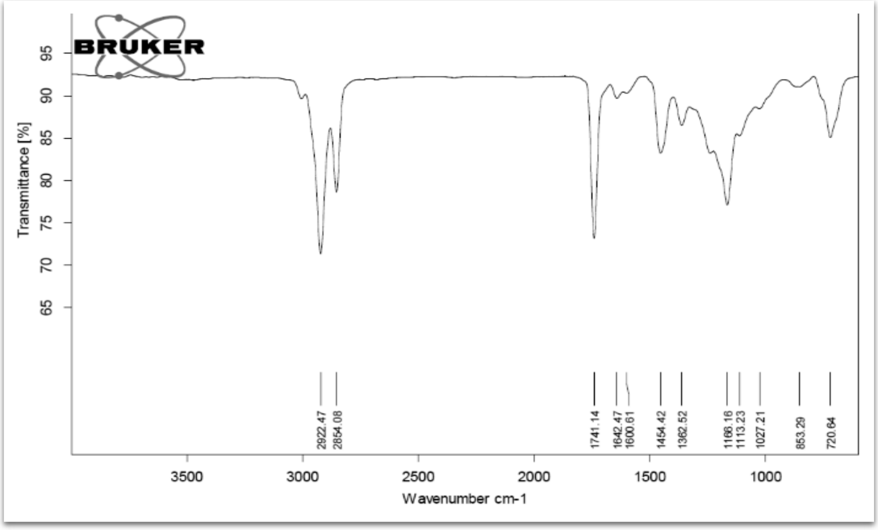

Fig. 1. Infrared spectra of Pongamia pinnata methyl ester.

The wave number from the infrared spectroscopy gives the functional groups present in the biodiesel, which is provided in Table 4. The spectroscopy analysis shows the presence of esters, which is the required biodiesel. Refer to Figures 13- and Tables 57- for spectroscopic results obtained for the required biodiesel.

Table 5. Infrared spectra analysis of *Pongamia pinnata* methyl ester.

Functional group	Wavenumber cm^{-1}	Bond
Alkanes	2922.47,2854.08 , 1454.42	C-H
Alkenes	1642.47	–C=C–
Aromatics	1600.61	C–C
Esters	1741.14	–C=O–
Nitro compounds	1362.52	N-O
Aliphatic amines	1241.79 and 1197.67	C-N
Alkyl halides	1113.23,1027.21	C-F
Aromatics, primary and secondary amines	853.29	C-H (Benzene)
Alkanes	720.64	C-H

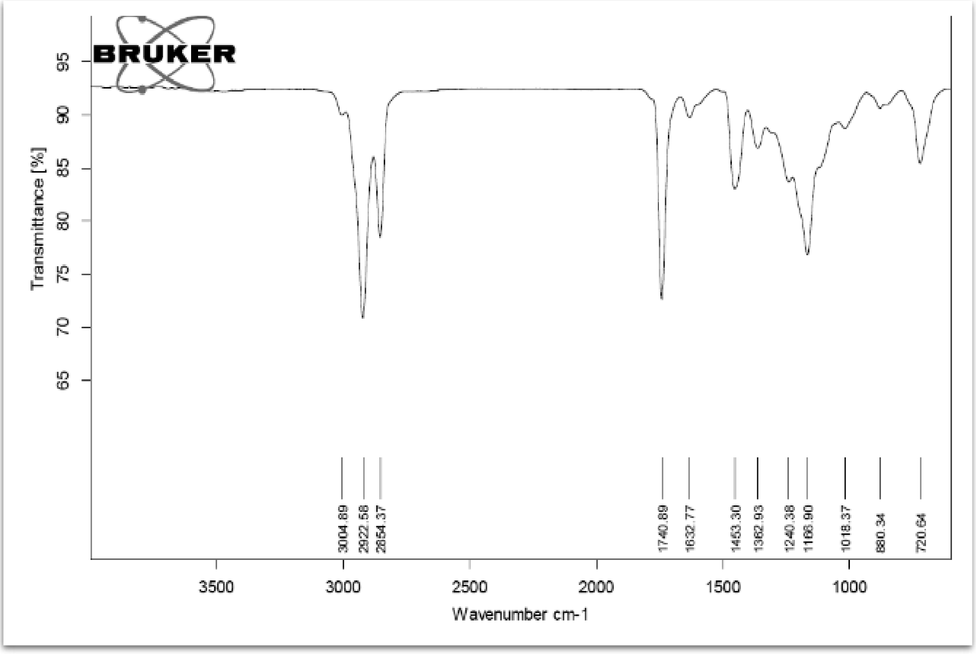

Fig. 2: Infrared spectra of *Calophyllum inophyllum* methyl ester.

The graph of transmittance versus wavenumber indicates the presence of different organic compounds in the biodiesel.

Table 5. Infrared spectra analysis of *Calophyllum inophyllum* methyl ester.

Functional group	Wavenumber cm-1	Bond
Aromatic rings	3004.89	C-H(Benzene)
Alkanes	2922.58 ,2854.37 , 1453.3	C-H
Esters	1740.89	C=O
Alkene	1632.77	=C-H
Nitro compounds	1362.93	N-O
Aliphatic amines	1240.38 and 1166.9	C-N
Alkyl halides	1166.9	C-H
Aromatics	880.34	C-H (Benzene)

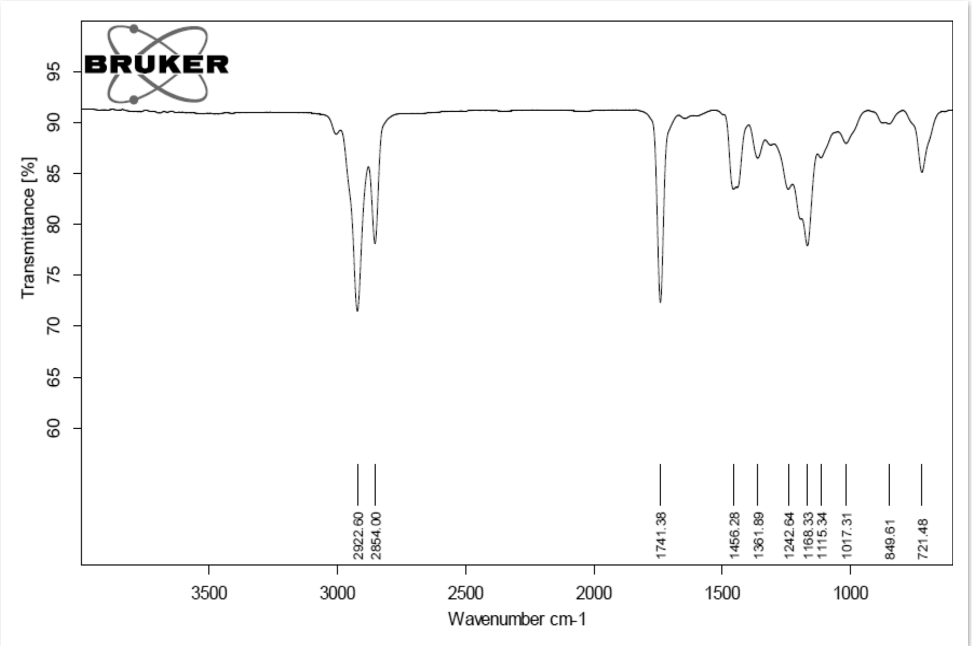

Fig. 3. Infrared spectra of waste cooking oil methyl ester.

Table 6. IR spectra analysis of waste cooking oil methyl ester.

Functional group	Wavenumber cm^{-1}	Bond
Alkanes	2922.60 ,2854 , 1456.28	C-H
Esters	1741.38	C=O
Nitro compounds	1361.89	N-O
Aliphatic amines	1242.64 and 1168.33	C-N
Alkyl halides	1115.34 ,1017.31	C-F
Aromatics	849.61	C-H (Benzene)
Alkanes	721.48	C-H

RESULTS AND DISCUSSIONS

In this section the biodiesels produced and tested in diesel engine have been compared for a particular blend. Mass fuel consumption, brake thermal efficiency, and brake specific fuel consumption of these biodiesels have been compared with respect to each other.

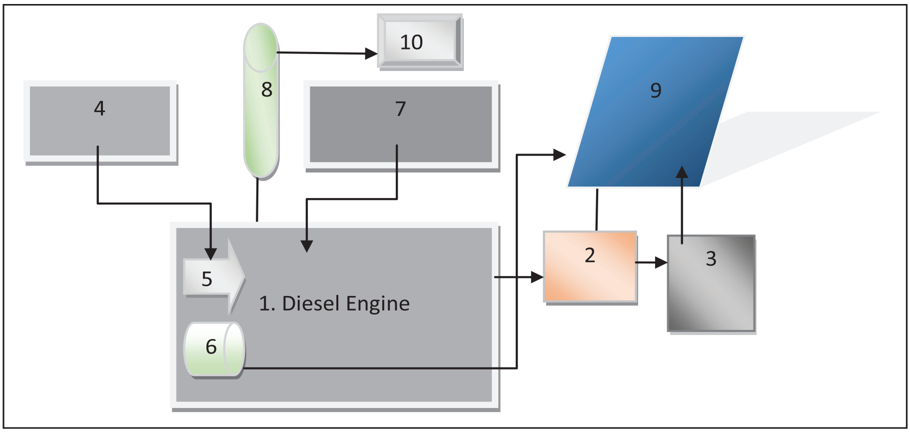

Fig. 4. Schematic outline of diesel engine used for experiment.

1. Diesel Engine
2. Alternator
3. Load cell
4. Fuel Tank
5. Fuel Injector
6. Pressure sensor
7. Air box
8. Thermocouple
9. Computer
10. EGT display

Table 7. Engine specifications.

Company	**Kirloskar**
Engine type	4-stroke single cylinder
Power	5.2kw
Bore	87.5 mm
Stroke	110 mm
Cooling	Water cooled
Speed	1500rpm
Compression ratio	17.5 :1
Fuel injection	Mechanical injection with injection timing 23° BTDC, 210 bar injection pressure.

Comparative study of various biodiesels for particular blends

B100: MF v/s BP

It can be observed from the graph (Figure 5) that fuel consumption of the Calophyllum inophyllum methyl ester (CIME) was found to be highest for PPME (Pongamia pinnata methyl ester) and WCOME (waste cooking oil methyl ester) showed almost the same but WCOME showed slightly lower fuel consumption than PPME. WCOME showed lowest fuel consumption among the biodiesels. WCOME showed lowest fuel consumption because of the higher calorific value of the WCOME compared to other biodiesels. Diesel has the lowest fuel consumption due to its higher calorific value compared to other biodiesels.

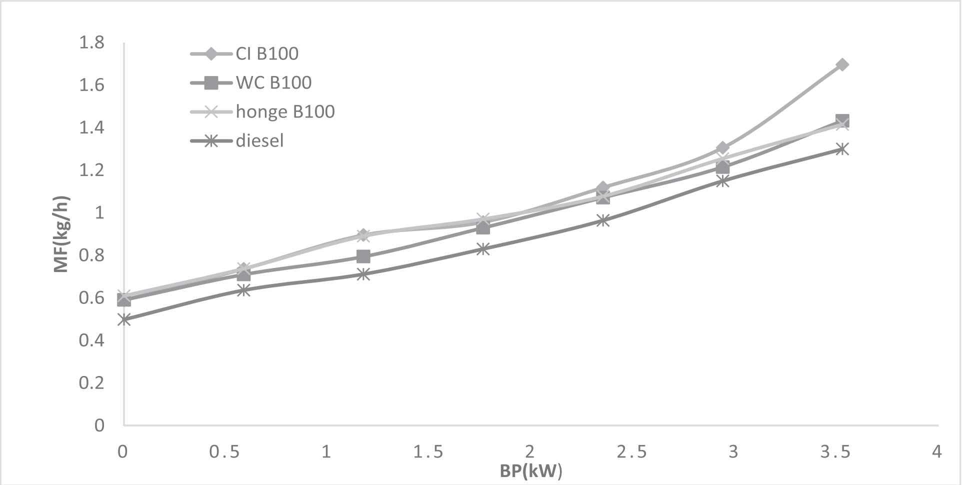

Fig. 5. MF v/s BP for B100 blends.

B100: BTE vs. BP

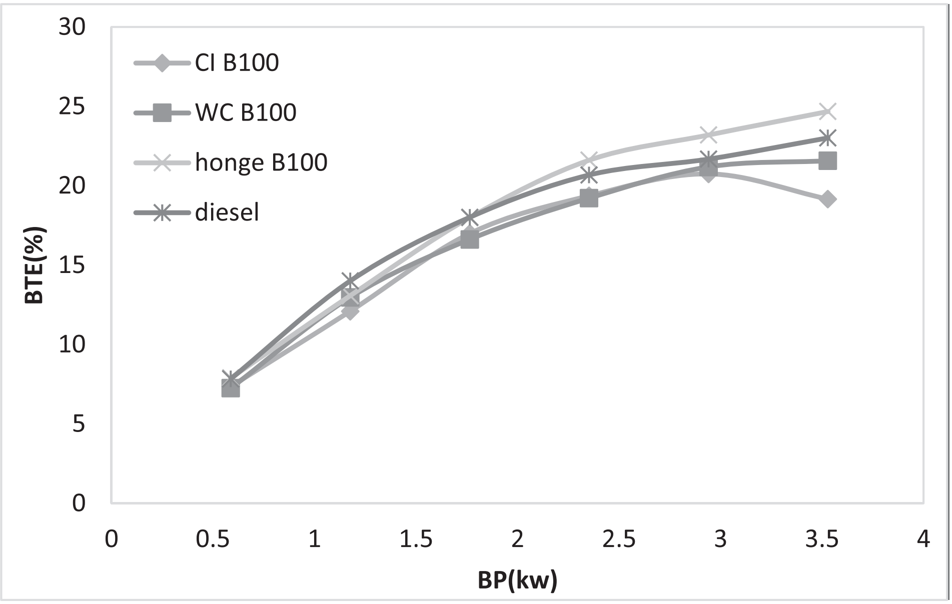

Fig. 6. BTE v/s BP for B100 blends.

It can be observed from the graph (Figure 6) that PPME showed highest BTE. BTE of CIME was found to be lowest comparatively. WCOME's BTE was found to be slightly higher than the BTE of CIME but lower than that of the remaining biodiesels for B100. Among all biodiesels PPME showed best BTE.

B100: BSFC vs. BP

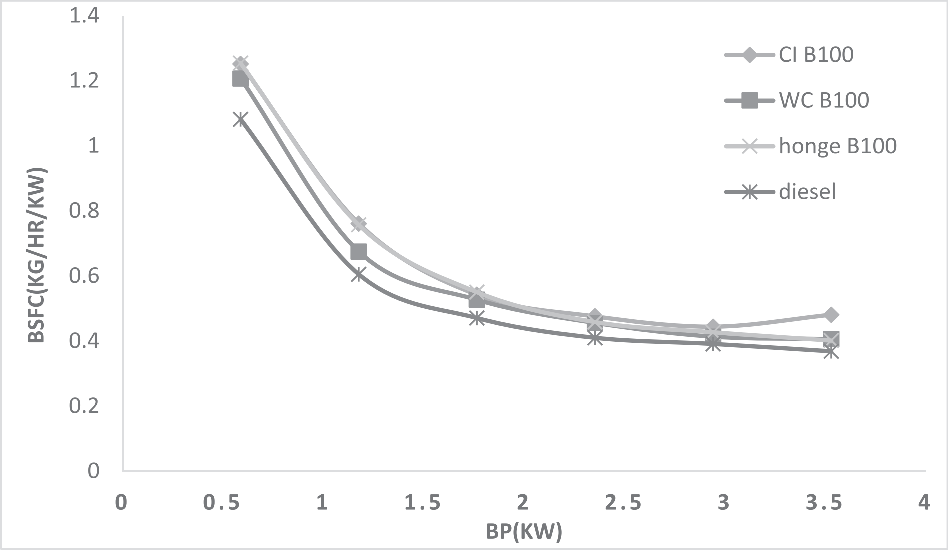

Fig. 7. BSFC v/s BP for B100 blends.

It can be observed from the graph (Figure 7) that BSFC of CIME was found to be highest. WCOME showed lowest BSFC among the biodiesels. Diesel showed lowest BSFC because of its higher calorific value.

B80: MF vs. BP

It can be found from the graph (Figure 8) that CIME and PPME showed almost similar fuel consumption and highest fuel consumption compared to other esters. The CIME and PPME are followed by WCOME, respectively. The lowest fuel consumption is for diesel because of its higher calorific value.

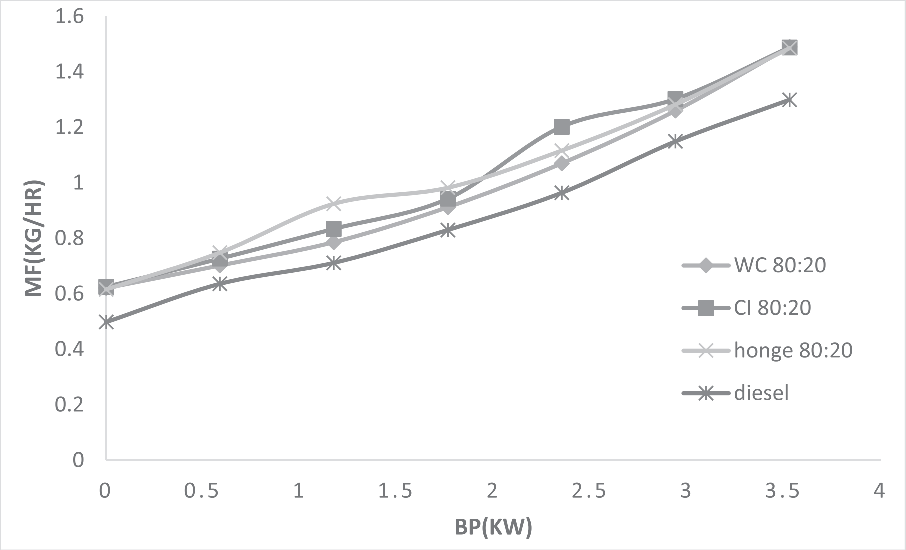

Fig. 8. BSFC v/s BP for B80 blends.

B80: BTE vs. BP

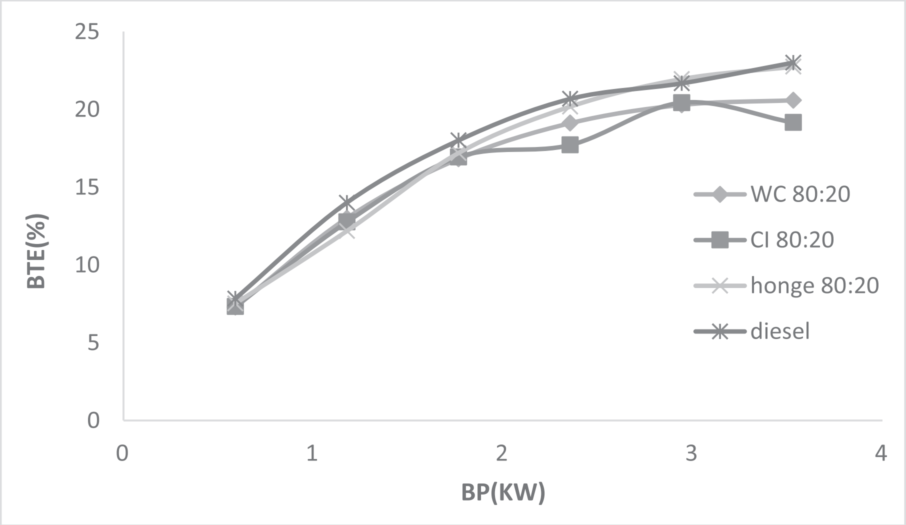

Fig. 9. BTE v/s BP for B80 blends.

The BTE of PPME (Figure 9) is followed by CIME and WCOME. CIME and WCOME showed similar BTE but BTE of CIME found to be slightly higher compared to WCOME at higher brake power. The best biodiesel for this blend was found to be PPME.

B80: BSFC vs. BP

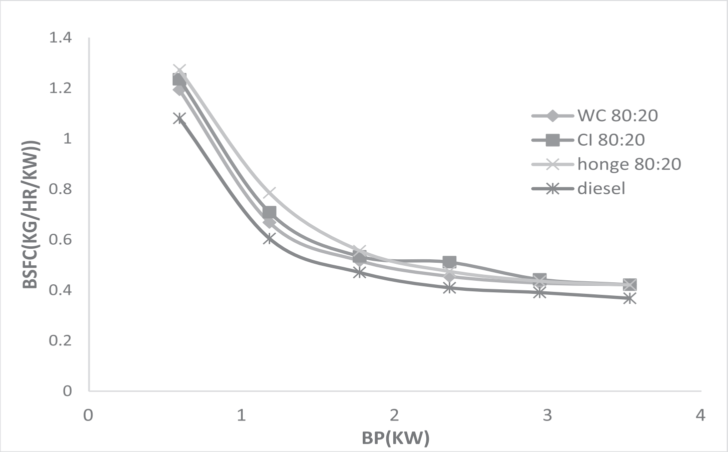

Fig. 10. BSFC v/s BP for B80 blends.

It was observed from the graph (Figure 10) that BSFC of WCOME was found to be lowest among the biodiesels compared. The highest BSFC was found for PPME, which was followed by IME, WCOME.

B65: MF vs. BP

Mass fuel consumption of honge is found to be highest for B65 blend. Mass fuel consumption of other biodiesels was found to be almost similar to each other as seen in Figure 11. Diesel showed lowest fuel consumption because of its higher heating value.

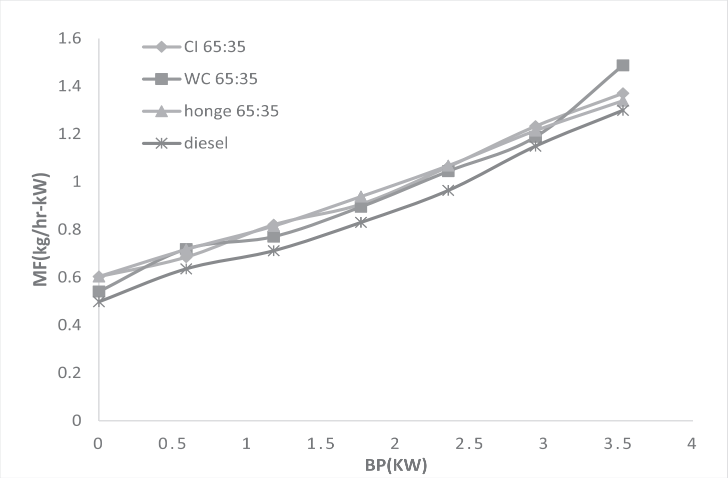

Fig. 11. MF v/s BP for B65 blends.

B65: BTE vs. BP

BTE of Calophyllum inophyllum and waste cooking oil is lowest, which can be observed from the above plot (Figure 12) .Also BTE of honge is highest. PPME is found to be the best biodiesel blend.

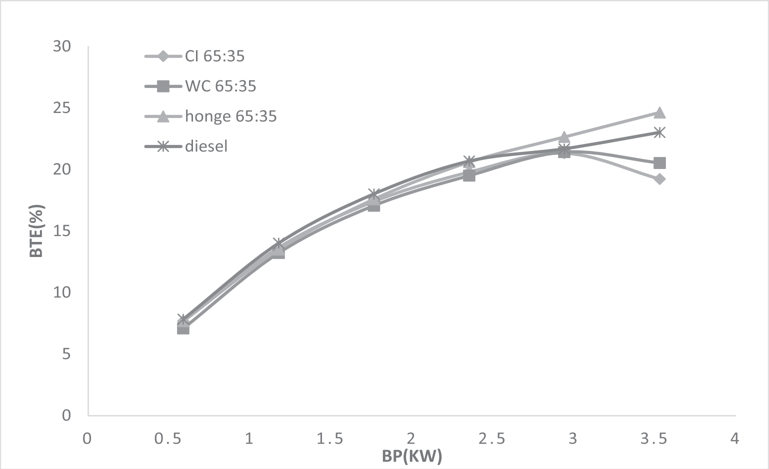

Fig. 12. BTE v/s BP for B65 blends.

B65: BSFC vs. BP

BSFC of PPME showed highest BSFC among considered biodiesels. BSFC of CIME and WCOME was found to be lowest among the biodiesels and almost similar to each other, observed from the graph (Figure 13). Diesel has the lowest BSFC because of its higher calorific value.

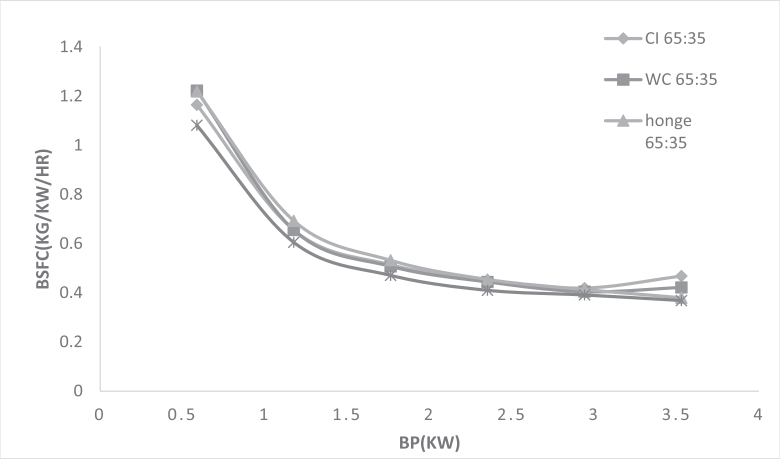

Fig. 13. BSFC v/s BP for B65 blends.

B50: MF vs. BP

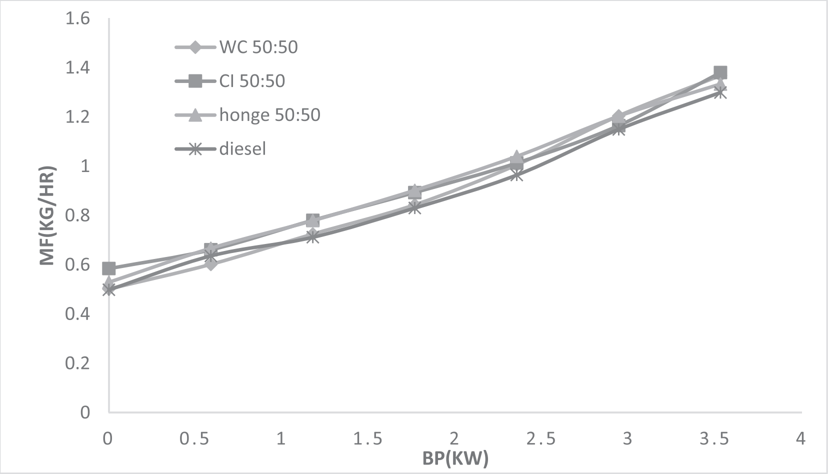

Fig. 14. MF v/s BP for B50 blends.

CIME and PPME showed almost similar fuel consumption and was the second highest among the biodiesels. WCOME showed the lowest fuel consumption among the biodiesels; refer to Figure 14. Diesel showed the lowest fuel consumption.

B50: BTE vs. BP

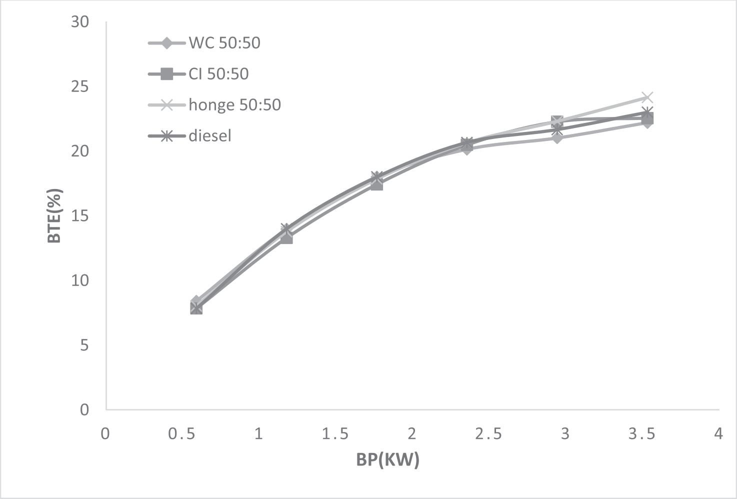

Fig. 15. BTE v/s BP for B50 blends.

PPME and CIME showed similar trend of BTE and highest among the considered biodiesels; refer to Figure 15. The BTE of PPME and CIME is followed by WCOME. The best biodiesels for this blend are PPME and CIME.

B50: BSFC vs. BP

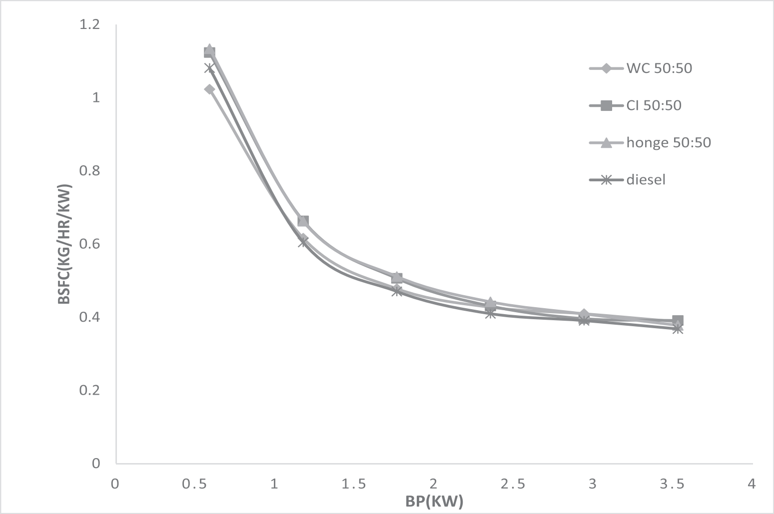

Fig. 16. BSFC v/s BP for B50 blends.

Diesel showed lowest BSFC because of its higher calorific value. WCOME showed lowest BSFC among the biodiesel blends as seen in Figure 16. CIME showed highest BSFC followed by PPME.

B50: EGT v/s BP

It can be observed from the graph (Figure 17) that WCOME has highest EGT at lower brake power and lowest EGT at higher brake power. PPME and CIME showed highest EGT at part load conditions.

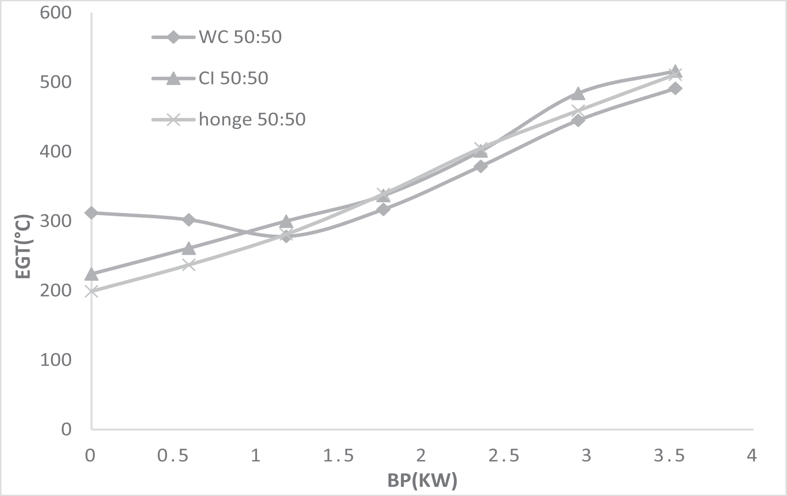

Fig. 17. EGT v/s BP for B50 blends.

B65: EGT v/s BP

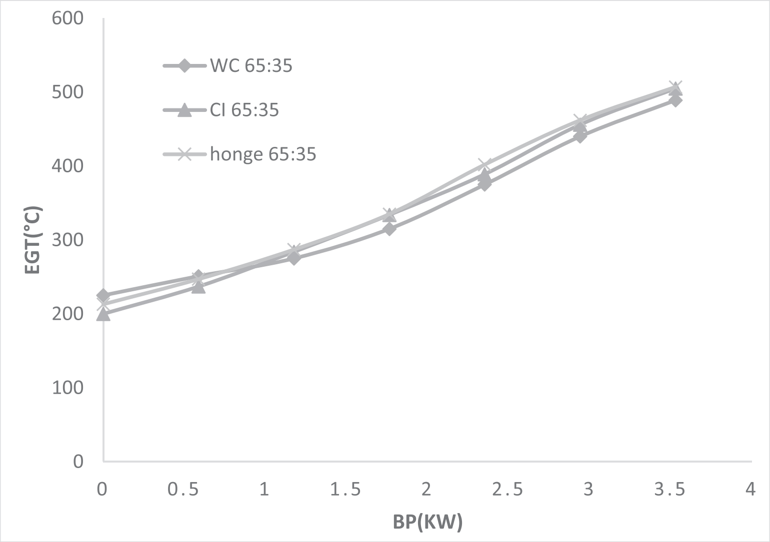

Fig. 18. EGT v/s BP for B65 blends.

It was observed from the graph (Figure 18) that PPME showed highest EGT variation. The second highest EGT variation was found by CIME. The lowest EGT was found in WCOME.

B80: EGT v/s BP

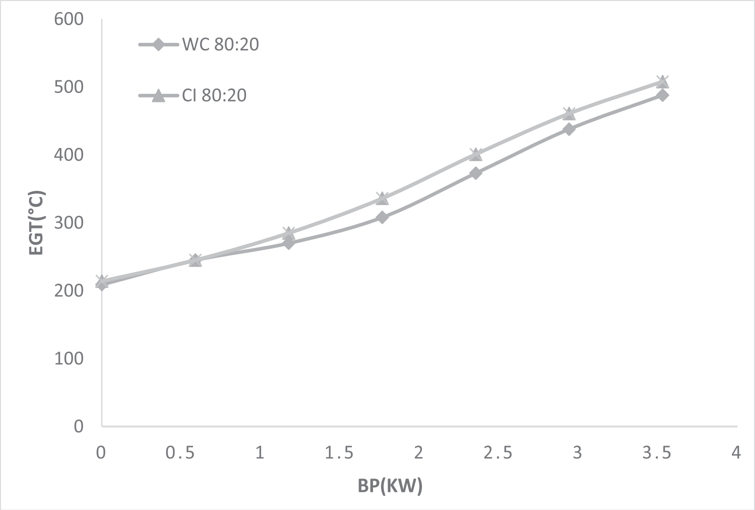

Fig. 19. EGT v/s BP for B80 blends.

It can be observed from the above plot (Figure 19) that the PPME and CIME blends have the highest EGT variation compared to other biodiesel blends. The EGT variation of PPME and CIME is followed by WCOME.

B100: EGT v/s BP

It can be observed from the above plot (Figure 20) that the PPME blend has the highest EGT variation compared to other biodiesel blends. The EGT variation of PPME is followed by CIME and WCOME, respectively.

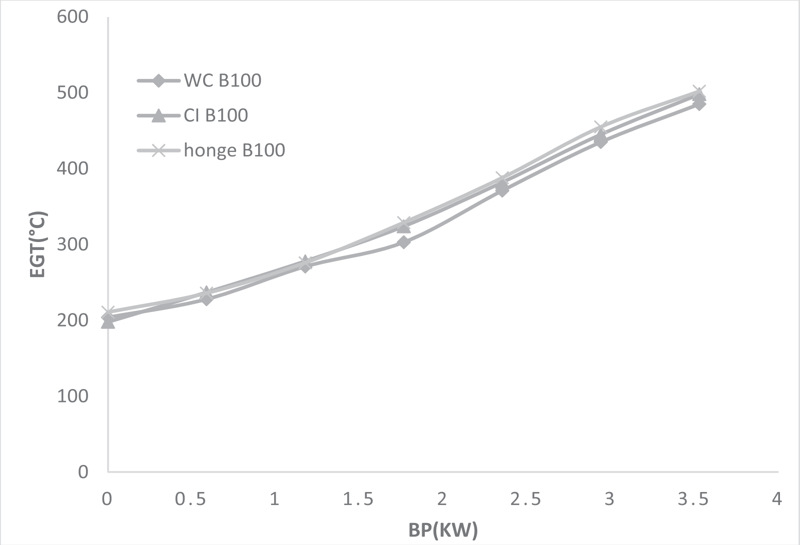

Fig. 20. EGT v/s BP for B100 blends.

CONCLUSION

In this article the research work carried out with biodiesel is staged as follows: four types of oils were selected from different sources (waste cooking oil, *Pongamia pinnata,* and *Calophyllum inophyllum*), and respective biodiesels are prepared using transesterification process. The prepared biodiesels are tested for their physical properties and chemical properties such as density, calorific value, viscosity, flash point, and fire point. Infrared spectroscopy test was conducted for prepared biodiesel to find out the chemical composition of the biodiesel. Each biodiesel prepared is blended with diesel in the ratios B50 (50% biodiesel - 50% diesel), B65 (65% biodiesel - 35% diesel), B80 (80% biodiesel - 20% diesel), and B100 (100% biodiesel) to form a total of 12 blends.

- *Pongamia pinnata* methyl ester was concluded to be the best fuel among the 100% biodiesels, which showed highest BTE characteristics at different load conditions. The results of infrared spectroscopy conducted for Pongamia pinnata methyl ester show complete conversion of free fatty acid into methyl esters.
- *Pongamia pinnata* methyl ester was concluded to be the best fuel for B80 blends, which showed highest BTE characteristics at different load conditions.
- *Pongamia pinnata* methyl ester was concluded to be the best fuel for B65 blends, which showed highest BTE characteristics at different load conditions.
- *Pongamia pinnata* methyl ester and Calophyllum inophyllum methyl ester were found to be the best fuels for B50 blends, which showed highest BTE characteristics at different load conditions.

- The EGT trend for each biodiesel with different blend showed a decrease in EGT with increasing biodiesel percentage since complete combustion occurs because of the presence excess oxygen in biodiesels, which is also proved by infrared spectroscopy.
- Among 100% biodiesels BSFC of waste cooking oil methyl ester was found to be the lowest compared to other biodiesels.
- Among B80 blends BSFC of waste cooking oil was found to be the lowest compared to other blends.
- Among B65 blends BSFC of waste cooking oil and Calophyllum inophyllum methyl esters was found to be the lowest compared to other blends.
- Among B50 blends BSFC of waste cooking oil methyl esters was found to be the lowest compared to other blends.

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إنتاج الديزل الحيوي من مصادر مختلفة ودراسات مقارنة لأداء المحركات باستخدام مزائج مختلفة من الديزل الحيوي

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الخلاصة

تم إنتاج وقود الديزل الحيوي من بونغيميا بيناتا «Pongamia Pinnata»، كالفيلوم إينوفيلوم «Calophyllum Inophyllum» ومخلفات زيت الطهي ذات محتوى مختلف من الأحماض الدهنية الحرة وذلك باستخدام مراحل مختلفة من عملية الأسترة التبادلية. تم اكتشاف الخصائص الفيزيائية والكيميائية للديزل الحيوي، مثل: نقطة الوميض، نقطة الاحتراق، القيمة الحرارية، الكثافة واللزوجة جنباً إلى جنب مع التحليل الطيفي باستخدام الأشعة تحت الحمراء. أُجريت دراسات على أداء المحرك باستخدام وقود الديزل الحيوي بنسبة 100٪ من مصادر مختلفة وباستخدام مزائج مثل B50 و B65 و B80 مضافة إلى الديزل. وعند المقارنة بين زيوت الديزل الحيوية وجدنا أن زيوت الديزل المُصنعة من بونغيميا بيناتا أظهرت أعلى كفاءة حرارية للفرامل (BTE) من بين أنواع الديزل الحيوي الأخرى المُستخدمة. وبالنسبة لاستخدام مزيج B65، أظهر الديزل الحيوي المُصنع من بونغيميا بيناتا أعلى BTE. وبالنسبة لمزيج B50، قدم الديزل الحيوي من بونغيميا بيناتا وكالفيلوم إينوفيلوم أعلى BTE. وعندما تمت مقارنة هذه المزائج مع نوع معين من الديزل الحيوي، أظهر B50 أداء أفضل من جميع الجوانب لمختلف أنواع ومزائج الديزل الحيوي المستخدمة.