



## Characteristics of fish oil biodiesel with the impact of diesel fuel addition on a CI engine

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### Abstract

The present study focuses on the optimization in the use of non-petroleum fuel derived from waste fish oil fuels, as a replacement for petroleum diesel fuel for compression ignition engine. The study comprises of comparison between results of fish oil biodiesel-diesel blends on a compression ignition engine. Fuel properties such as viscosity, density, heat value of fuel, cetane number and a flash point of fish oil biodiesel and its blends with diesel were studied. The fish oil biodiesel (60, 40, 20, and 0%) – diesel (40, 60, 80 and 100%) are blended at volume basis. The results shows reduction in thermal efficiency, temperature, particulate matter and nitrogen oxides emission; while showing an increase in higher specific fuel consumption, ignition delay, carbon dioxide and smoke emissions. The B20 fuel blend improves BTE by 4.7%, CO<sub>2</sub> emissions has been increased by 2.56%, while SFC is lowered by 7.92% as compared to diesel fuel. In biodiesel blend (B20) the highest reduction in NO<sub>x</sub> by 14.9%, particulate by 4.22% is observed although smoke emission slightly rises with increase in fish oil in the blends, as compared to diesel fuel.

### Nomenclature

BP	Brake power
SFC	Specific fuel consumption
BSN	Bosch smoke number
C	Constant
CN	Cetane number
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
CP	Cylinder pressure
CPP	Cylinder peak pressure
CR	Compression ratio
EGT	Exhaust gas temperature
FCR	Fuel consumption rate
FOME	Fish oil methyl ester
HHV	Higher heating value
HRR	Heat release rate
ID	Ignition delay

LHV	Lower heating value
MRPR	Maximum rise of pressure rate
P	Pressure
PM	Specific particulate matter
rpm	Revolutions per minute
NO <sub>x</sub>	Nitrogen oxides
UHC	Unburned hydrocarbons
D100	100% diesel
B20	80% diesel + 20% fish oil biodiesel
B40	60% diesel + 40% fish oil biodiesel
B60	40% diesel + 60% fish oil biodiesel
B100	100% fish oil biodiesel

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## 1. Introduction

Environmental pollution increases rapidly due to an increase in automobile vehicles in the world. In this respects need to clean energy sources due to concerns of destructive ecological pollution such as more emissions of carbon dioxide and greenhouse gases [1]. The country developed depends on fuel sources, while fossil fuel resources limited in the world. Now day needs to eco-friendly and less distractive alternative energy source for full fill demands of energy consumption in the world [2]. Many previous studies reported different alternatives energy sources such as fish oil [2-3], palm oil [4], waste cooking oil [5], rubber seed oil [6], linseed oil [7], jatropha [8], mahua oil [9], and alcohol [9, 10].

Adeoti et al. [11] performed experiments on a test engine using fish oil and its blends with bunker oil. The results showed non-newtonian behavior and fuel properties. Rajak and Verma [2] performed numerically on a diesel engine using Diesel RK model. Results showed that reduction in smoke emission and particulate matter of five different categories biodiesels. Jiaqiang E et al. [3] studied on diesel engine using fish oil biodiesel, and its blends with diesel examined the characteristics of the test engine. Bhaskar et al. [12] studied the characteristics of test engine using fish oil biodiesel and its blends. Conclude that B20 perform optimum result same as diesel fuel with less UHC, CO and soot emissions. Gnanasekaran et al. [14]. Performed experiments on a diesel engine power of 4.4 KW with different load and different injection timings which are 21-27.0° b TDC. Studied characteristics of test engine using fish oil biodiesel and its blends (20, 40, 60, 80 and 100%). Results showed that the reduction in NO<sub>x</sub>, UHC, and CO emissions while a marginal improvement in smoke and CO<sub>2</sub> emissions with an increase in the percentage of fish oil.

Ushakov et al. [16] research on a diesel engine and used fish oil and low sulfur marine gas oil as a fuel. Studied engine characteristics. Swaminathan et al. [17] research on a diesel engine with exhaust gas recirculation evaluate the performance of the test engine and conclude that maximum percentage of reduction in exhaust emissions when used fish oil blends with (EGR) and 2% of additive [17]. Cherng-Yuan Lin et al. [18] research on a diesel engine and evaluate characteristics of the test engine using fish

oil and methyl alcohol biodiesel. Behcet [19] performed experiments on a test engine with full loading condition at varying engine speed (1000-2500 rpm) using anchovy fish oil and diesel fuel blends. Evaluate the characteristics of the diesel engine.

Gharehghani et al. [20] studied on a diesel engine fueled with fish oil biodiesel-diesel blends and evaluated the diesel engine characteristics. Godiganur et al. [21] performed experiments on a diesel engine with constant engine speed and different engine loads and evaluated engine characteristics. The results showed that the reduction in exhaust emission and no significant variation in engine performance using fish oil biodiesel. Hajamini et al. [22] studied biodiesel production from waste fish oil using sulfonated activate carbon in the catalyst. They found to be properties of biodiesel. Shivaraja et al. [23] evaluated the optimum technique of hybrid multi-criteria decision making and engine characteristics. Results showed that better engine performance with hybrid multi-criteria decision-making method. Adeoti and Hawboldt [24] studied the production of biodiesel from fish oil for the CI engine and evaluated properties of biodiesel. Mrad et al. [25] performed experiments on the diesel engine at the same engine speed with varying engine loads. Conclude that improved in thermal efficiency using B20 and B40 blends with higher engine load. Other hands reduction in CO, PM, and UHC, while the more NO<sub>x</sub> emission as compared to diesel fuel.

From the previous studied, it is obvious that numerous studies have been done on the investigation of different categories of biodiesels in which few investigations were carried out with fish oil biodiesel and biodiesel production from waste fish oil. The objective of this research work is to explore the technical feasibility by using waste fish oil biodiesel and theirs blends in the CI engine. In the present study, biodiesel is produced from the waste fish oil by transesterification process and their different blends are prepared (B20, B40, B60 and B100). The test were performed at different engine load (25%, 50%, 75%, and 100%) with constant engine speed and compression ratio of 1500 rpm and 18.5 and their diesel engine characteristics were examined without any modification in engine setup.

**2. Material and Producer of experiments**

*2.1 Biodiesel production from waste fish oil*

*2.1.1 Fish oil biodiesel*

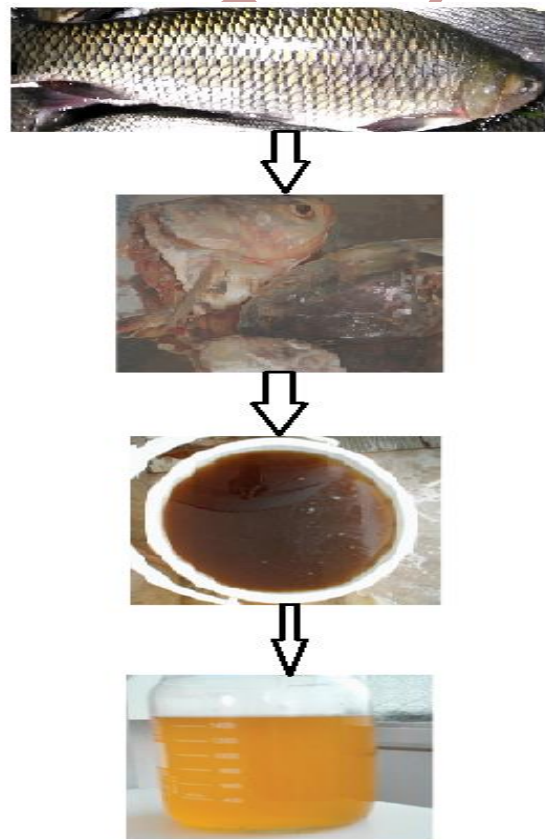
Fish oil biodiesel produced from waste fish oil by transesterification process. Approximately 1000 ml waste fish oil was taken in a flask and heated up to 75 °C with the help of heating coil and oil was stirring with minimum speed. The reactants were the raw fish oil, potassium hydroxide (KOH), and ethanol (C<sub>2</sub>H<sub>5</sub>OH). The response variables delivered into concern for the transesterification process were reaction temperature, reaction time, and alcohol to oil molar ratio. Catalyst (KOH) was mixed quickly with ethanol. By using a funnel, mixture poured into the flask. Flask was closed so that no air was trapped in the container Mixture was stirred approximate 60 minutes. Moreover, allow to settle down for 12 hours. These process turned oil into esters, so we easily separate the glycerol. Easter (biodiesel) floated on the top and glycerol settled down at the bottom of the flask due to density difference. Glycerol washed by warm de-ionised water until cleaning is not done. The excess water in the ester phase was separated by evaporation process under controlled conditions. Easter added in the ratio of 20%, 40%, 60%, 80% with diesel to transform it is as biodiesel which is known as diesel blends.

Similarly, methanol (CH<sub>3</sub>OH) based esterification; the reaction's done quickly and efficiently break down. It forms methyl ester layers above and glycerol layers lower. In ethanolysis, these emulsions are difficult to separate and complex to purification, but it is more stable. Hence our attention towards ethanol which is used for transesterification of waste fish oil to producing biodiesel. Biodiesel production process and steps from waste fish oil are given in Fig.1.

**Advantegous of fish oil biodiesel compared to other fuels**

- It is easily available throughout the world.
- Production cost of fish oil biodiesel is lower than other biodiesel fuel.
- Fuel density of fish oil biodiesel is lower than other biodiesel fuels such as bael oil, beaf oil chicken fat karanja, poultry fat etc.

- Fish oil have more calorific value compare to other fuel i.e. bael oil, microalgae, neem methyl ester, palm oil etc.
- Fish oil have low viscosity at 40°C compared to other fuels i.e. diesel, bael oil, Calophyllum methyl ester, jojoba oil, rubber Seed oil etc.
- Fish oil have more cetane number to other fuel i.e. cotton seed oil, croton methyl ester, linseed methyl ester, rubber seed oil, bael oil etc.



**Fig. 1.** (a) Fish oil extraction

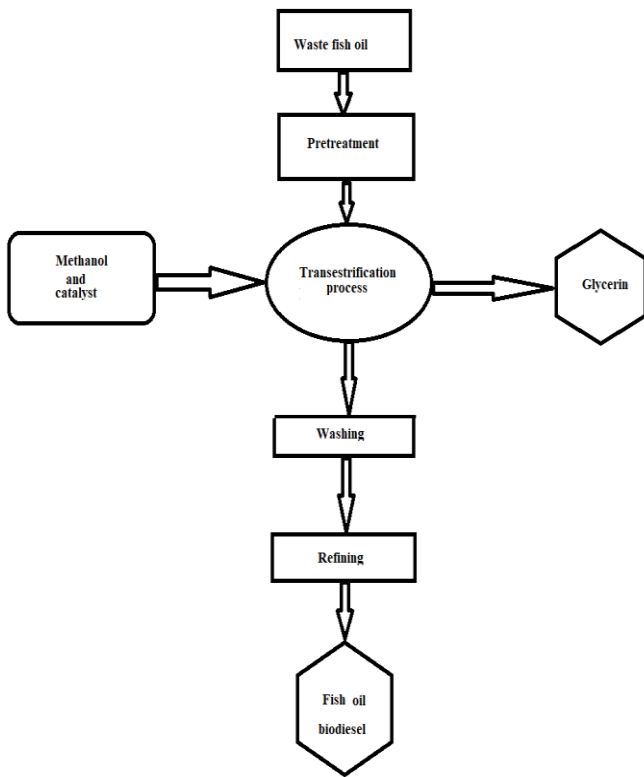


Fig. 1. (b) Biodiesel production process and steps

2.2 Fuel properties

Table 1 shows some of the previous study was used of fish oil biodiesel for evaluating diesel engine characteristics, and Table 2 shows the fuel properties of fish oil biodiesel-diesel blends was used to assessing diesel engine characteristics in the present study. The fish oil methyl ester biodiesel has been selected for the present study because of its richness in the various regions of India.

Table 1. Chemical-physical properties of fish oil biodiesel used previous researchers

LHV (MJ/kg)	viscosity at 40 °C (mm <sup>2</sup> /s)	density (kg/m <sup>3</sup> )	cetane number	flash point (°C)	ref.
37.58	4.4	866	56	142	3
37.79	5.2	890	52.5	157	12
40.057	4.741	885	52.6	114	14
41	4.2	870-880	51.5	164-173	20
42.241	4	880	-	176	21
45.1	1.7	825	57	57	25

Table 2. Chemical-physical properties of diesel, fish oil and their blends used in the present research work

Fuel properties	D10	B100	B20	B40	B60
LHV (MJ/kg)	43.5	39.5	42.6	41.84	41.048
Viscosity at 40 °C (mm <sup>2</sup> /s)	3.5	4.6	65	7	3.904
Density (kg/m <sup>3</sup> )	830	876	839.	848.9	858.192
CN	48	53	49.0	50.06	51.064
Flash point (°C)	74	140.5	438	5	113.9

2.3 Experimental procedure

The experiments were performed using a single cylinder, four-stroke, water cooled, diesel engine with rated power 3.7 KW whose layout is shown in Fig. 2. Further gneral technical information for this experimental setup can be found in Table 3. The test engine used high-pressure universal rail injection system. The test engine was coupled with eddy current dynamometer by direct coupling system. The mass of the test fuel was measured before and after each 20 min trial at each load. From the data, the fuel mass consumption was evaluated. Testo-350 flue gas analyzer was used to measured exhaust gas emission. Exhaust gas passes through the probe of the gas analyzer to check the level of CO<sub>2</sub>, CO, UHC and NO<sub>x</sub> emissions. A type K thermocouple was used to measure the gas temperature at a different position in the experiment setup. Filter based smoke meter was used to measure the level of smoke emission. After achieving a steady state condition of the test engine, performed the experiments and repeated three times to increase accuracy, precision and minimize the error. The experiment was performed at a constant engine speed of 1500 rpm and compression ratio of 18.5 with different engine loads (25, 50, 75, and 100%). All the experiments were performed at a room temperature of 25°C (± 1°C). In the present study, diesel engine fueled with different blends of fish oil biodiesel and diesel fuel were used. Uncertainty established the accuracy of the experiment. The detailed of uncertainty within the setup as shown in table 4.

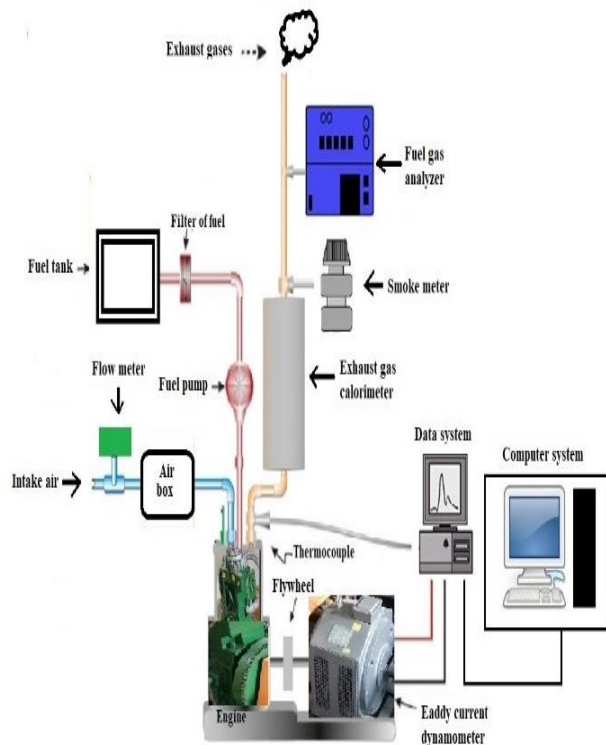


Fig. 2. Layout of test engine

Table 3. Engine key specifications for test engine

Key specification	value
Making	legion brother
Number of cylinder	single
Stroke (mm) x Bore (mm)	110 x 80
Compression ratio	18.5:1
Speed (rpm)	1500
Connecting rod length (mm)	235
Fuel pressure (bar)	500-800
Power rated (KW) & cooling	3.7 & water
Inlet valve open and closed	5° b TDC and 35° a BDC
Outlet valve open and closed	35.5° b BDC and 5° a TDC
Timing	23.0° b TDC

Table 4. Details of instrumentation

Instruments	uncertainty (%)
Temperature sensor	±0.15
Pressure sensor	±0.5
Speed sensor	±1.0
Encoder	±0.2
Load cell	±0.2
Burette for fuel measurement	±1.0
Smoke	±1.0

Portable flue gas analyser

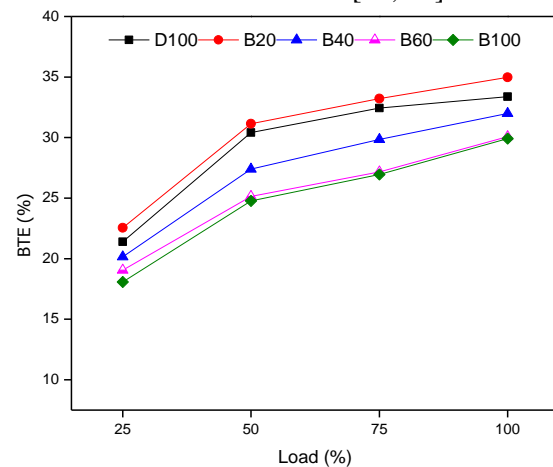
CO	±0.3
CO <sub>2</sub>	± 1.0
HC	±0.1
O <sub>2</sub>	±0.3
NO <sub>x</sub>	± 0.5

### 3. Results and discussion

#### 3.1. Performance analysis

##### 3.1.1 Brake thermal efficiency (BTE)

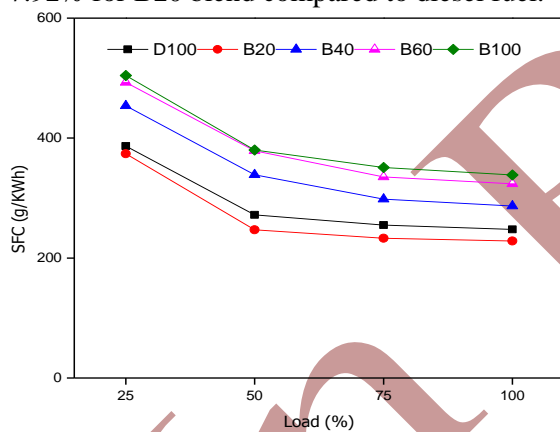
Fig. 3 represents the variation of BTE with engine loads for diesel fuel (D100), B20, B40, B60 and fish oil biodiesel (B100). The brake thermal efficiency for tested fuels has lower value at low engine load, with the increasing load it increased and higher value at higher engine load. The value of BTE changes from 21.398% to 33.385% with an increase in engine load (from 25 to 100%). Similarly for FOME changes from 18.08% to 34.7%. For B20 changes from 22.558% to 34.7%. B40 varies from 21.16% to 29.987%. B60 varies from 19.063% to 30.083%. BTE reduced with increase in the percentage of biodiesel in blends due to decreasing heat value of blend. BTE decreased with increased blend ratio due to lesser ignition delay period and a lesser delay period lead to the earlier start of combustion. The shorter ignition also increases the compression work and heat loss due to reducing the efficiency of the engine. In the real lag, more air carriers with the fuel [14, 15].



**Fig. 3.** BTE verses engine load

3.1.2. *specific fuel consumption (SFC)*

Fig. 4 represents the variation of SFC with different engine loads, for diesel fuel (D100), B20, B40, B60 and fish oil biodiesel (B100). The fuel consumption for tested fuels has a higher value at low engine load, with the increasing load it reduced and lesser value at higher engine load from the present study. The inversely proportional of SFC and BTE at engine load for diesel, FOME and its blends. SFC is higher for biodiesel and its blend due to higher density and lower heat value of biodiesel as compared to diesel fuel [12]. At 100% loading condition, the SFC (g/KWh) of diesel (D100) by 247.89, FOME (B100) by 338.62, B20 by 228.24, B40 by 286.88, B60 by 323.82 respectively. BSFC decreased with increasing engine load and higher for FOME biodiesel, while the lower for the blend (B20) as compared to diesel fuel. SFC is lower by 7.92% for B20 blend compared to diesel fuel.

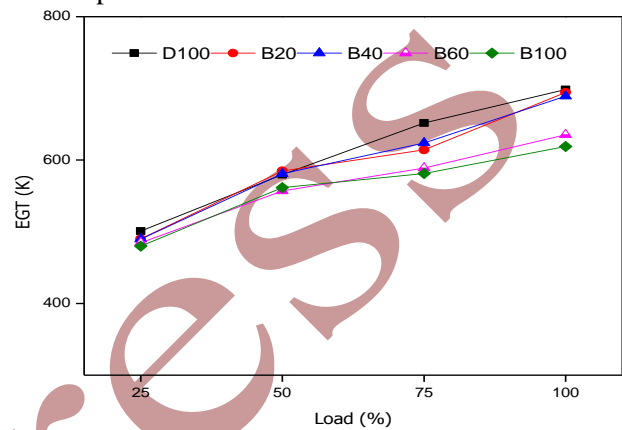


**Fig. 4.** SFC verses engine load

3.1.3. *Exhaust gas temperature (EGT)*

Fig. 5 represents the variation of EGT with engine loads for diesel, fuel (D100), B20, B40, B60 and fish oil biodiesel (B100). The lower exhaust gas temperature was measured to be 618.8 K for B100 as compared to 698.5 K for diesel fuel (D100). The EGT for tested fuels has a lower value at low engine load, with the increasing load it improved and high value at higher engine load from the present study. The EGT has described the combustion heat of the tested fuel at ignition period. The higher viscosity of fuel leads to slow burning. The EGT was obtained lower for FOME biodiesel, and its blend compared to diesel due

to more percentage of oxygen contents within the fuel and indications to before burning and lower calorific value of biodiesel fuel [15, 20]. At full load, the EGT (K) found to be 698.5, 694.33, 689.2, 635.3 and 618.8 for diesel (D100), B20, B40, B60 and biodiesel (B100) respectively. The EGT for this case is about 10.0% lower for FOME biodiesel (B100) due to advanced oxygen contents and inferior heating value as compared to diesel fuel.

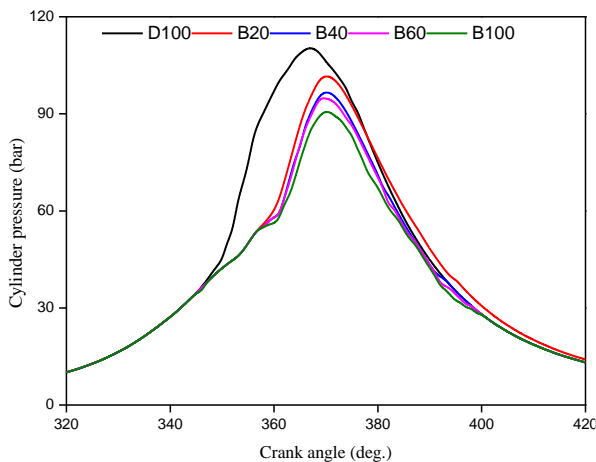


**Fig. 5.** Exhaust gas temperature verses engine load

**3.2 Combustion analysis**

3.2.1. *Cylinder pressure (CP)*

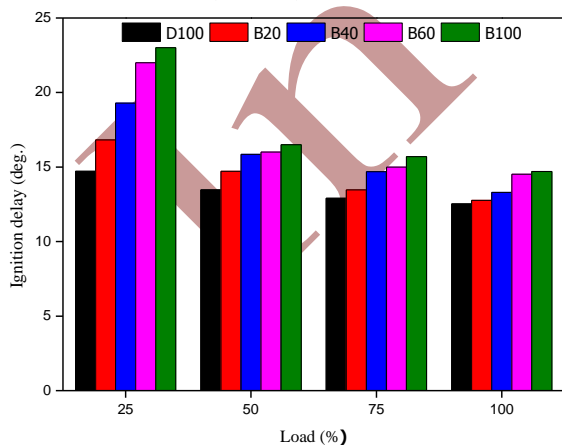
Fig. 6 represents the variation of cylinder pressure with crank angle, for the diesel fuel (D100), B20, B40, B60, and B100 at load full load. The cylinder peak pressure (CPP) is maximum for diesel fuel compared to biodiesel and its blends because of low viscosity and high instability of diesel fuel. Therefore it plays an important role in atomization rate and an air/fuel fraternization. CPP is maximum for diesel because of shorter ignition delay, so fraternisation of air/fuel done well at the time of ignition. The CPP for biodiesel and its blends is lower because of increase in ignition delay because of high viscosity and low instability due to low vaporization so increase physical and chemical lag [14, 15, 20]. From the figure cylinder peak pressure are 110.4, 101.8, 96.7, 95.0 and 90.8 for diesel fuel (D100), B20, B40 B60 and fish oil biodiesel (B100) respectively.



**Fig. 6.** Cylinder pressure versus crank angle at full load

3.2.2. Ignition delay period (ID)

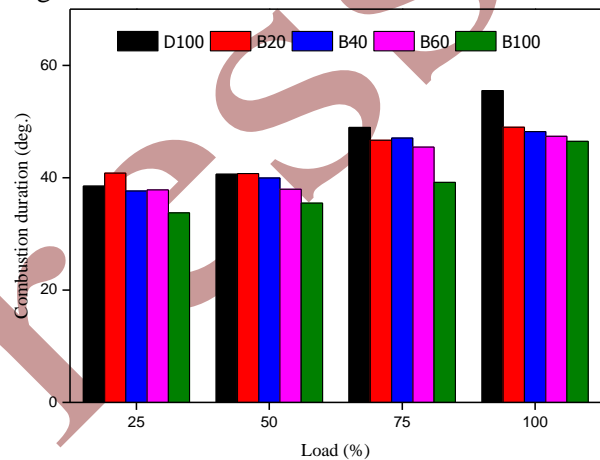
Ignition delay is defined by time duration between the start of injection to the beginning of combustion. It consists of two lag (a) Physical lag (b) Chemical lag. In real lag fuel atomise, vaporise adequately mixed with air. In chemical lag chemical reactions take place. Ignition delay period has a reverse relation with cylinder pressure and heat rejection rate [26]. Fig. 7 represents the difference of ID with load, for diesel fuel (D100), B20, B40, B60, and B100 at load full load. At full load condition, the value of ID (degree) for pure diesel is 12.54, and for biodiesel is 14.7, and for B20, B40 and B60 are 12.76, 13.29, and 14.52.



**Fig. 7.** Ignition delay verses engine load

3.2.3. Combustion duration (CD)

Fig. 8 shows the variation of CD with different engine load, for diesel fuel (D100), B20, B40, B60, and B100 at load full load. At full load condition combustion duration of biodiesel is lower than diesel due to biodiesel have higher contents of oxygen, so it improves the combustion quality and combustion rate [15]. Experimental results showed that the increased combustion duration with an increasing load. At full loading condition CD (degree) for diesel (D100) is 55.5, for biodiesel (B100) is 46.47, and for B20, B40 and B60 are 48.98, 48.18 and 47.3. CD of diesel is 16.27% higher than biodiesel.



**Fig. 8.** Combustion duration versus engine load

3.2.4. Maximum rise of pressure rate (MRPR)

Fig. 9 shows the variation of MRPR at different engine loads for the diesel, FOME and its blends. It is clear from the figures that the MRPR increases with increase load. At full load, the value of MRPR are 5.1, 3.4, 2.8, 2.3, and 1.9 for diesel (D100), B20, B40 B60 and B100 respectively. The value of MRPR is lower by 33.6% for B20 blend as compared to diesel fuel. The pre-mixed burning stage is less rigorous for biodiesel leads to a lower maximum rise of pressure rate [14]. The MRPR increases with increase load and reductions with an increases percentage of alternative fuel within the blends.

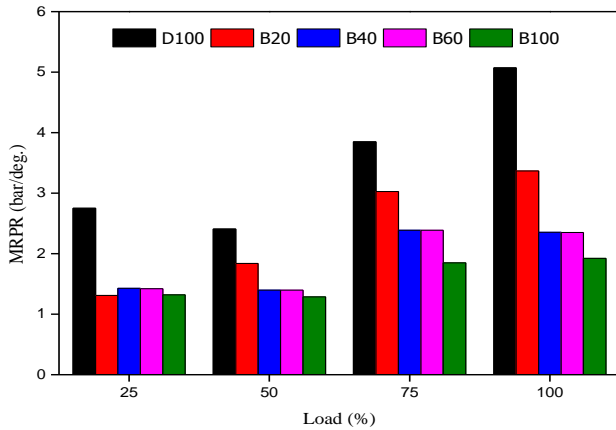


Fig.9. MRPR versus engine load

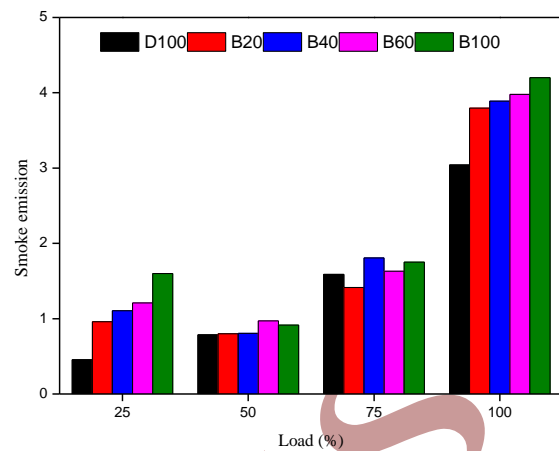


Fig. 10. Bosch smoke number versus engine load

### 3.3 Emission analysis

#### 3.3.1. Smoke analysis

Fig. 10 represents that Bosch smoke number (BSN) emission with different engine load for the diesel fuel (D100), B20, B40, B60, and B100 at load full load. At full load smoke emission has high at higher engine load due to more quantity of fuel burned for high power output [5]. The BSN emission increased with an increasing in engine load for diesel fuel, B20, B40, B60 and biodiesel (B100) at all engine loads. The more amount of fuel entered into the cylinder so produce rich mixture due to this incomplete burning of fuel smoke increased. Experimental results show that for biodiesel and its blends are higher than diesel fuel. Because of the high viscosity and low volatility of biodiesel that is the main reason for the inappropriate mixing of fuel and air. Due to the high molecular weight of biodiesel smoke increases [14, 15]. At full load BSN values for D100 by 3.05, B20 by 3.8, B40 by 3.89, B60 by 3.98 and B100 by 4.2. Biodiesel produces smoke emission by 37.7% higher than the diesel fuel.

#### 3.3.2. Carbon dioxide emission (CO<sub>2</sub>)

Fig. 11 represents the variation CO<sub>2</sub> emission with different loads for diesel fuel (D100), B20, B40, B60, and B100 at load full load. It is clear from the figures that the CO<sub>2</sub> decreases with increasing load due to cylinder temperature increase, which helps to better burning of a hydrocarbon of fuel [14]. For D100, the CO<sub>2</sub> (g/kWh) decreases from 1249.5 at low load to 800.59 at higher engine load. For B20, the CO<sub>2</sub> decreases from 1181.7 at low load to 721.1 at higher load and B100, the CO<sub>2</sub> decreases from 2615.8 at low load to 979.5 at higher engine load. The CO<sub>2</sub> is higher for fish oil biodiesel and increases with increase blend ratio. The burning process is better for biodiesel as compared to diesel, foremost to a more elevated CO<sub>2</sub>. The CO<sub>2</sub> decreases with increasing load in engine and increases with increasing fraction of biodiesel within the mixtures.

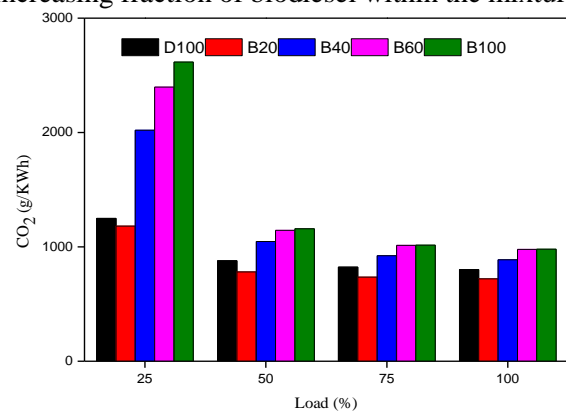


Fig. 11. Carbon dioxide emission verses engine load

#### 3.3.3. Nitrogen oxides emission (NO<sub>x</sub>)



Fig. 12 represents the variation of NO<sub>x</sub> emission with different loads for diesel fuel (D100), B20, B40, B60, and B100 at load full load. It is clear from the figures that the NO<sub>x</sub> increases with load due to cylinder temperature increased which it helps to burn off a hydrocarbon of fuel and better combustion process [15, 16, 17].

For D100, the NO<sub>x</sub> (ppm) increases from 500.0 at low load to 2999.8 at higher engine load. For B20, the NO<sub>x</sub> increases from 400.0 at low load to 2552.5 at higher engine load and B100; the NO<sub>x</sub> increases from 110.0 at low load to 2200.0 at higher engine load. The NO<sub>x</sub> is lower for fish oil biodiesel as compared to diesel fuel and decreases with intensification in mixtures. The ignition process is better for biodiesel compared to diesel, foremost to an inferior NO<sub>x</sub>. The NO<sub>x</sub> increasing with increase load and decreases with an intensification fraction of biodiesel within the mixtures.

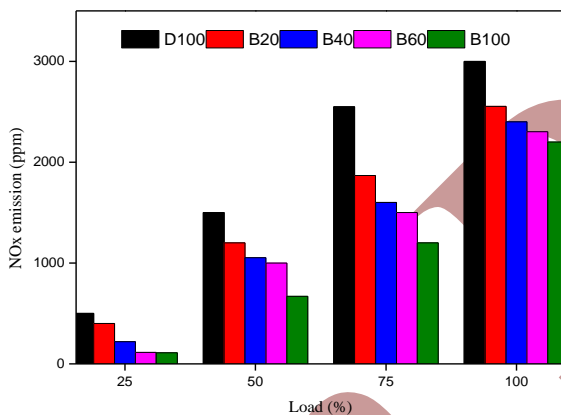


Fig. 12. NO<sub>x</sub> emission verses engine load

### 3.3.4. Particulate matter emission (PM)

Fig. 13 represents the variation of PM with different loads for diesel fuel (D100), B20, B40, B60, and B100 at load full load. It is clear from figures that the PM decreases as increasing in engine load due to oxygen contents in the molecular structure, which is recovers vaporization of fuel [22, 25]. For D100, the PM (g/kWh) decreases from 1.862 at low load to 0.71 at full engine load. For B20, the PM decreases from 1.61 at low load to 0.68 at full engine load and B100; the PM decreases from 1.13 at low load to 0.57 at full engine load. The PM is inferior for fish oil biodiesel and decreases with increasing fraction of biodiesel within the mixtures. The burning process is better for biodiesel due to

higher contents of oxygen, foremost to an inferior PM emission.

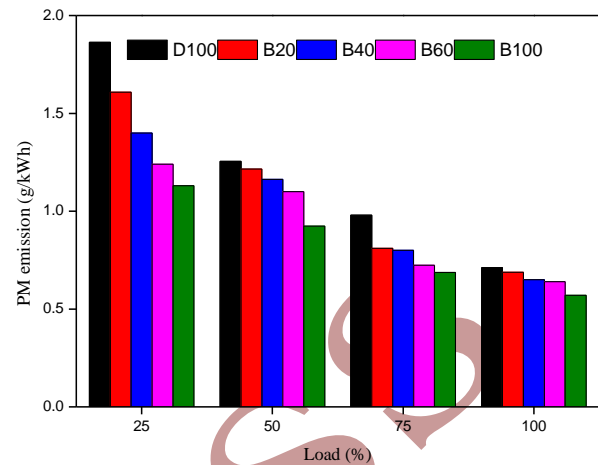


Fig. 13. PM emission versus engine load

## 4. Conclusion

In this study, the effect of fish oil methyl ester on a single cylinder engine characteristics were investigated. The highlights of this present study are as follows:

- Fish oil biodiesel produced from waste fish renewable resources.
- BTE decreases with increase in fraction of FOME biodiesel within the mixtures and slightly higher for B20 blend.
- SFC decrease with increase in fraction of FOME biodiesel within the mixtures, SFC of B20, 7.92% lower than diesel at full loading condition.
- ID increases with increase in fraction of FOME biodiesel within the mixture. ID of B20 is 1.75% more than diesel fuel at full loading condition.
- EGT is obtained to be lower than diesel and increases with increasing load in the engine. EGT of B20 is 0.6% lower compare to diesel fuel at full loading condition.
- NO<sub>x</sub> emission decreases with increase in fraction of FOME biodiesel within the mixtures. NO<sub>x</sub> emission shows reduction by 14.9% for B20 and 26.6% for B100 were observed at full engine load as compared to diesel.

- PM emissions decreases with an increase in fraction of FOME biodiesel within the mixtures. 4.22% and 19.7% reduction in PM emissions were observed for B20 and B100 with respective diesel fuel at 100% load.
- Smoke emissions slightly increases with an increase in biodiesel blends. 24.59% smoke emission increase when B20 compare to diesel fuel. And 37.7% smoke emission increases when B100 compare to the diesel fuel at full loading condition.

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