J. Comput. Appl. Res. Mech. Eng. Vol. 10. No. 2, pp. 325-336, 2021 *DOI: 10.22061/jcarme.2019.4737.1571*

SRTTU Journal of Computational and Applied Research in Mechanical Engineering jcarme.sru.ac.ir JCARME ISSN: 2228-7922

Research paper

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

Deepak Kumar Sharma and Tikendra Nath Verma*

Department of Mechanical Engineering, National Institute of Technology Manipur-795004, India

Article info:

Article history:

Received: 25/01/2019

Accepted: 10/06/2019

Revised: 12/06/2019

Online: 15/06/2019

Keywords:

Compression ignition engine,

Engine characteristics,

Fish oil biodiesel production

***Corresponding author:**
verma.tikks@gmail.com

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 in 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 show 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_2 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_x by 14.9%, particulate by 4.22% is observed although smoke emission slightly rises with an increase in fish oil in the blends, as compared to diesel fuel.

1. Introduction

Environmental pollution increases rapidly due to an increase in automobile vehicles in the world. In this respect, there is a necessity to clean energy sources due to concerns of destructive ecological pollution such as more emissions of carbon dioxide and greenhouse gases [1]. The development of any country depends on fuel sources, while fossil fuel resources are limited in the world. Now a days there is a need to eco-friendly and less distractive alternative energy source for full fill demands of energy consumption in the world. Rajak and Verma [2] performed numerically on a diesel engine using Diesel RK model. Results showed reduction in smoke emission and particulate matter of five different categories biodiesels. Many previous studies reported different alternative 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. Bhaskar et al. [12] studied the characteristics of a test engine using fish oil biodiesel and its blends. The concluded that B20 performs optimum result the same as diesel fuel with less UHC, CO and soot emissions. Gharehghani [13] carried out a comparative study of waste fish oil production also introduced an oil extraction machine. The study concludes that from one liter of fish oil 0.9liter biodiesel produced. Gnanasekaran et al. [14-15] performed experiments on a diesel engine power of 4.4 KW with different load and different injection timings which are 21-27.0º b TDC. They studied the characteristics of test engine using fish oil biodiesel and its blends (20, 40, 60, 80 and 100%). Results showed reduction in NO_x, UHC, and CO emissions while a marginal improvement in smoke and CO_2 emissions with an increase in the percentage of fish oil was observed.

Ushakov et al. [16] studied a diesel engine and used fish oil and low sulfur marine gas oil as a fuel and the engine characteristics. Swaminathan et al. [17] investigated a diesel engine with exhaust gas recirculation and evaluated the performance of the test engine and concluded that maximum percentage of reduction in exhaust emissions takes place when fish oil blends are used with (EGR) and 2% of additive [17]. Cherng-Yuan Lin et al. [18] did a research on a diesel engine and evaluated the 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; they evaluated the characteristics of the diesel engine.

Gharehghani et al. [20] studied 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 the 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 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. They concluded thermal efficiency improved using B20 and B40 blends with higher engine load. Other hands reduction in CO, PM, and UHC, while the more NO_x 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, while few investigations were carried out with fish oil biodiesel and biodiesel production from waste fish oil. The objective of this research is to explore the technical feasibility of using waste fish oil biodiesel and its blends in the CI engine. In the present study, biodiesel is produced from the waste fish oil by transesterification process and its different blends are prepared (B20, B40, B60 and B100). The test was performed at different engine load (25%, 50%, 75%, and 100%) with constant engine speed and compression ratio of 1500 rpm and 18.5 and the 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

Fish oil biodiesel was produced from waste fish oil by transesterification process. Approximately 1000 ml waste fish oil was taken in a flask and was heated up to 75 ℃ with the help of heating coil, while the oil was stirring with minimum speed. The reactants were the raw fish oil, potassium hydroxide (KOH), and ethanol (C_2H_5OH). 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, the mixture was poured into the flask. The flask was closed so that no air was trapped in the container. The mixture was stirred approximately for 60 minutes. Moreover, it was allowd to settle down for 12 hours. This process turned oil into esters, so we easily separated the glycerol. Easter (biodiesel) floated on the top and glycerol settled down at the bottom of the flask due to density difference. Glycerol was 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, known as diesel blends [26].

Similarly, the methanol (CH_3OH) based esterification; the reaction's done quickly and efficiently breaks 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 was given to 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 Figs. 1 and 2.

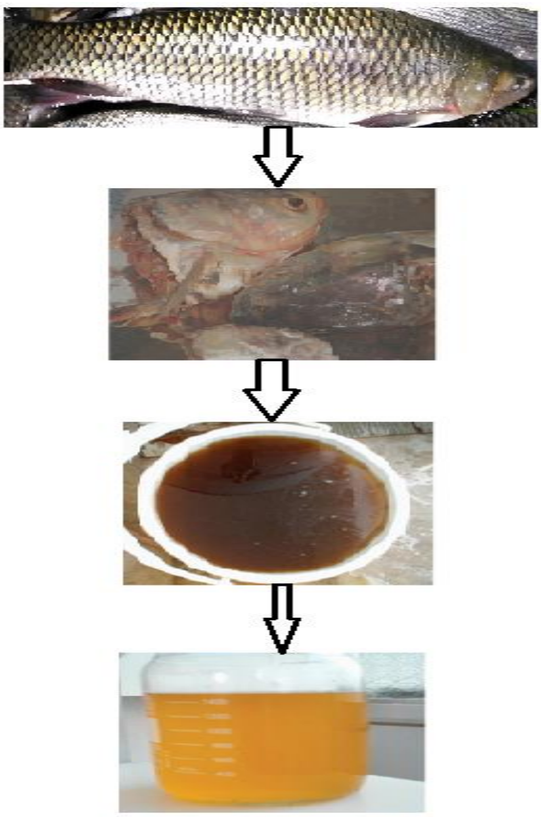

Fig. 1. Fish oil extraction.

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 has more calorific value compare to other fuels, i.e. bael oil, microalgae, neem methyl ester, palm oil etc.
- Fish oil has 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 has more cetane number to other fuel, i.e. cotton seed oil, croton methyl ester, linseed methyl ester, rubber seed oil, bael oil etc.

2.2. Fuel properties

Table 1 shows some of the previous studies that used fish oil biodiesel for evaluating diesel engine characteristics. Table 2 shows the fuel properties of fish oil biodiesel-diesel blends used to assess 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 various regions of India.

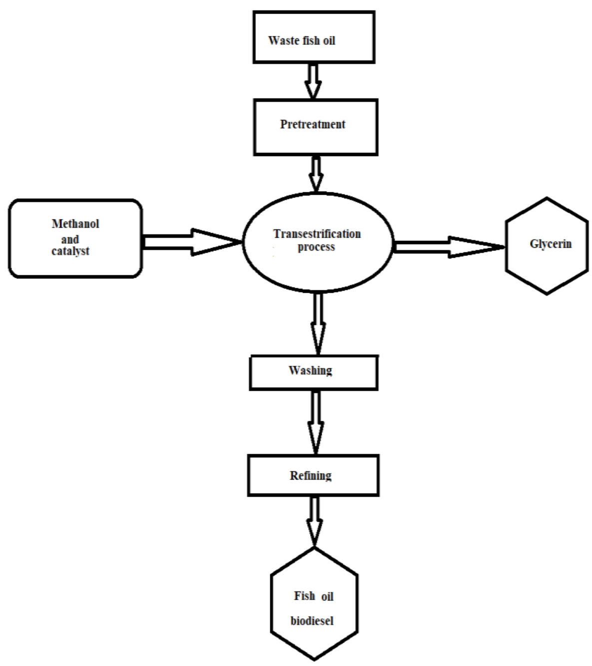

Fig. 2. Biodiesel production process and steps.

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. 3. 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_2, CO, UHC and NO_X 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, the experiments were performed and repeated three times to increase the accuracy and precision; and minimize the error [27-31]. 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 is shown in Table 4.

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

LHV (MJ/kg)	Viscosity at 40 °C (mm²/s)	Density (kg/m³)	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	D100	B100	B20	B40	B60
LHV (MJ/kg)	43.5	39.5	42.665	41.847	41.048
Viscosity at 40 °C (mm²/s)	3.5	4.6	3.697	3.904	4.124
Density (kg/m³)	830	876	839.603	848.99	858.192
CN	48	53	49.0438	50.065	51.064
Flash point (°C)	74	140.5	87.3	100.6	113.9

Table 3. Engine key specifications for test engine.

Key specification	Value
Making	Legion brother
Number of cylinders	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

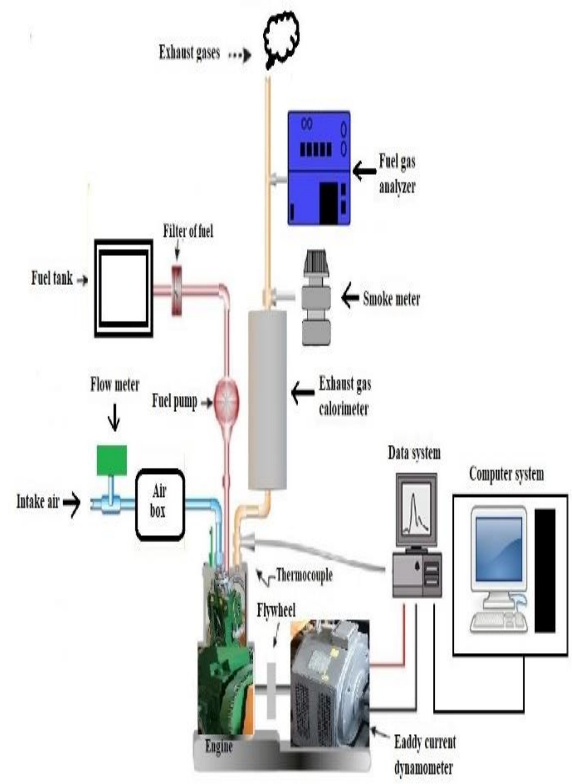

Fig. 3. Layout of test engine.

3. Results and discussion

3.1. Performance analysis

3.1.1. Brake thermal efficiency (BTE)

Fig. 4 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 is seen [32]. The value of BTE changes from 21.398% to 33.385% with an increase in engine load (from 25 to 100%). Similarly for FOME, it changes from 18.08% to 34.7%. For B20, it 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 an 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 is carried with the fuel.

3.1.2. specific fuel consumption (SFC)

Fig. 5 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 is seen from the present study. There is 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 [33]. At 100% loading condition, the SFC (g/KWh) of diesel (D100) are 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 is higher for FOME biodiesel, while it is lower for the blend (B20) as compared to diesel fuel. SFC is lower by 7.92% for B20 blend as compared to diesel fuel.

3.1.3. Exhaust gas temperature (EGT)

Fig. 6 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 is seen from the present study.

Table 4. Details of instrumentation.

Instruments	Uncertainty (%)
Temperature sensor	±0.15
Pressure sensor	±0.50
Speed sensor	±1.00
Encoder	±0.20
Load cell	±0.20
Burette for fuel measurement	±1.00
Smoke	±1.00
Portable flue gas analyser CO	±0.30
CO_2	±1.00
HC	±0.10
O_2	±0.30
NO_X	±0.50

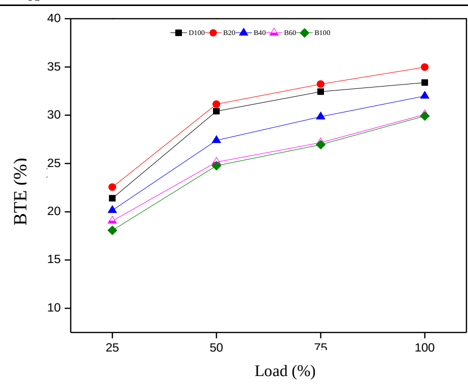

Fig. 4. BTE verses engine load.

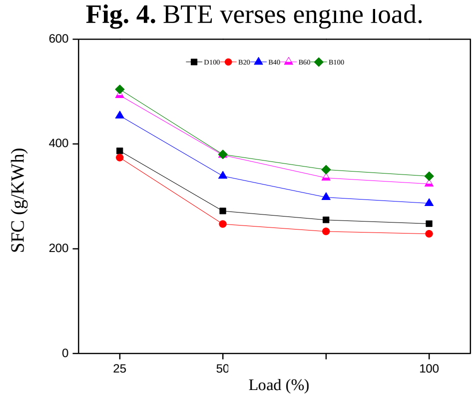

Fig. 5. SFC verses engine load.

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 [33, 34]. At full load, the EGT (K) was 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.

3.2. Combustion analysis

3.2.1. Cylinder pressure (CP)

Fig. 7 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 [35, 36].
CPP is maximum for diesel because of shorter ignition delay, so fraternisation of air/fuel was done well at the time of ignition. The CPP for biodiesel and its blends is lower because of an 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.

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 is 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 [37]. Fig. 8 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.

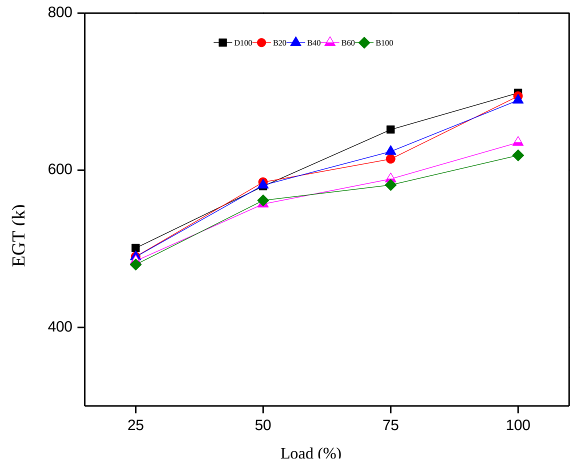

Fig. 6. Exhaust gas temperature verses engine load.

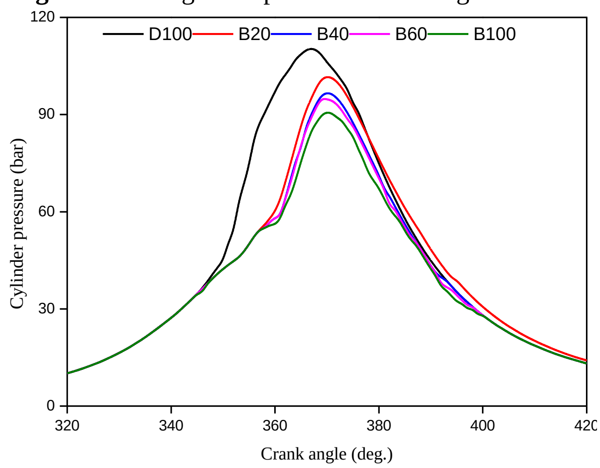

Fig. 7. Cylinder pressure versus crank angle at full load.

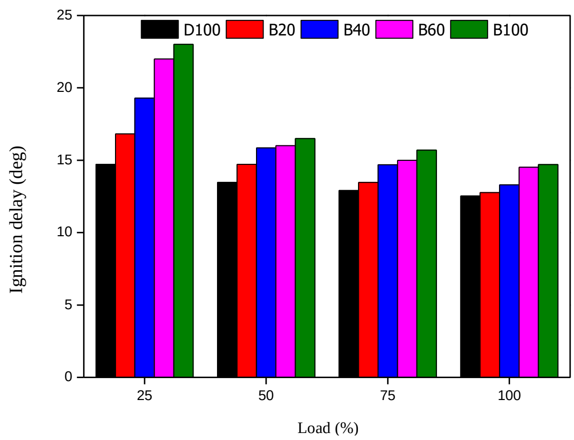

Fig. 8. Ignition delay verses engine load.

3.2.3. Combustion duration (CD)

Fig. 9 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, the combustion duration of biodiesel is lower than diesel due to the fact that biodiesel has higher contents of oxygen, so it improves the combustion quality and combustion rate [15, 37]. Experimental results showed that the combustion duration increased 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.

3.2.4. Maximum rise of pressure rate (MRPR)

Fig. 10 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, 38]. The MRPR increases with increase load and reduces with an increases percentage of alternative fuel within the blends.

3.3. Emission analysis
3.3.1. Smoke analysis

Fig. 11 repersents Bosch smoke number (BSN) emission with different engine load for the diesel diesel fuel (D100), B20, B40, B60, and B100 at load full load. At full load, smoke emission is high at higher engine load due to more quantity of fuel burned for high power output [38]. The BSN emission increased with an increase 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, produces rich mixture, and due to this incomplete burning of fuel smoke increased. Experimental results show that for biodiesel and its blends these are higher than diesel fuel. high viscosity and low volatility of biodiesel are the main reasons 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 are by 3.05, B20 by 3.8, B40 by 3.89, B60 by 3.98 and B100 by 4.2 respectively. Biodiesel produces smoke emission by 37.7% higher than the diesel fuel.

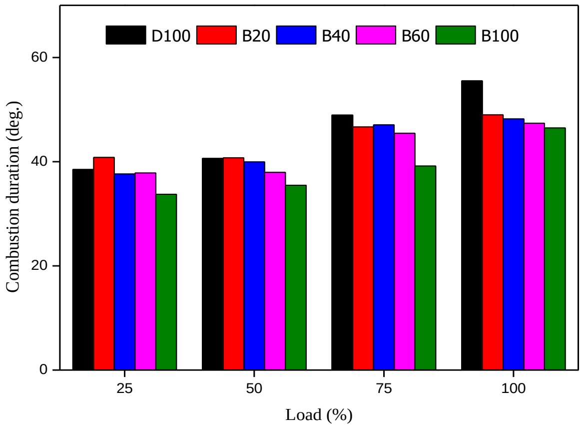

Fig. 9. Combustion duration versus engine load.

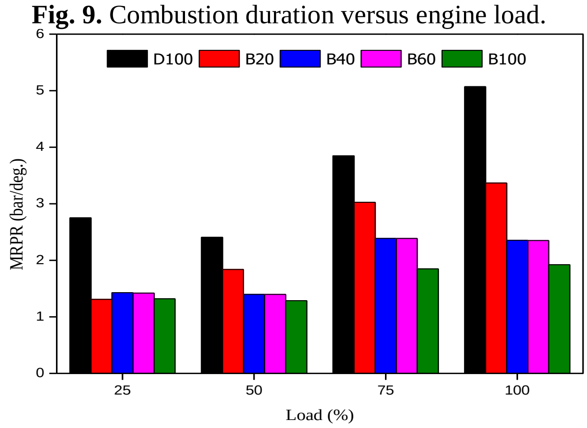

Fig. 10. MRPR versus engine load.

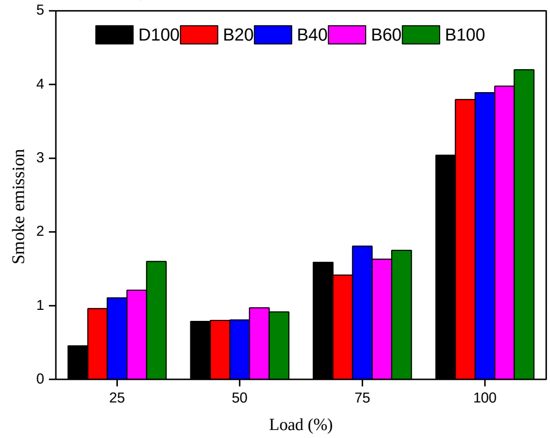

Fig. 11. Bosch smoke number versus engine load.

3.3.2. Carbon dioxide emission (CO_2)

Fig. 12 represents the variation CO_2 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_2 decreases with increasing the load due to cylinder temperature increase, which helps the better burning of a hydrocarbon of fuel. For D100, the CO_2 (g/kWh) decreases from 1249.5 at low load to 800.59 at higher engine load. For B20, the CO_2 decreases from 1181.7 at low load to 721.1 at higher load and B100, the CO_2 decreases from 2615.8 at low load to 979.5 at higher engine load. The CO_2 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_2. The CO_2 decreases with increasing load in engine and increases with increasing fraction of biodiesel within the mixtures [39, 40].

3.3.3. Nitrogen oxides emission (NO_X)

Fig. 13 represents the variation of NO_x 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_x increases with load due to cylinder temperature increased which helps to burn off a hydrocarbon of fuel and better combustion process.

For D100, the NO_x (ppm) increases from 500.0 at low load to 2999.8 at higher engine load. For B20, the NO_x increases from 400.0 at low load to 2552.5 at higher engine load and B100; the NO_x increases from 110.0 at low load to 2200.0 at higher engine load. The NO_x 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_x. The NOx increases with increase load and decreases with an intensification fraction of biodiesel within the mixtures [41, 42].

3.3.4. Particulate matter emission (PM)

Fig. 14 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 engine load due to oxygen contents in the molecular structure, which recovers vaporization of fuel. 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 [43].

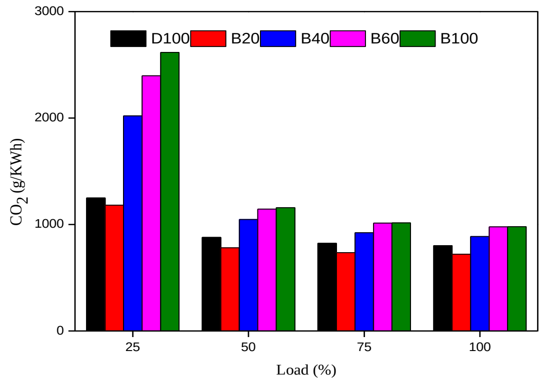

Fig. 12. Carbon dioxide emission verses engine load.

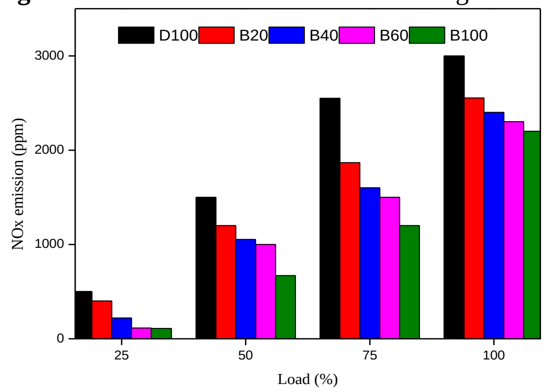

Fig. 13. NO_X emission verses engine load.

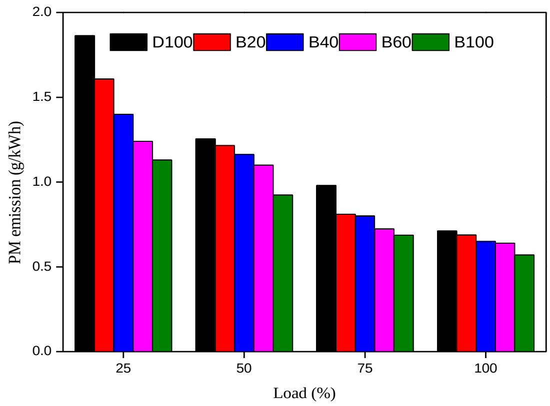

Fig. 14. PM emission versus engine load.

4. Conclusions

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 an increase in fraction of FOME biodiesel within the mixtures and slightly higher for B20 blend.
- SFC decreases with an increase in fraction of FOME biodiesel within the mixtures, SFC of B20, is 7.92% lower than diesel at full loading condition.
- ID increases with an 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_X emission decreases with increase in fraction of FOME biodiesel within the mixtures. NO_X 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 was observed for B20 and B100 with respective diesel fuel at 100% load.
- Smoke emissions slightly increase with an increase in biodiesel blends. 24.59% smoke emission increases when B20 was compared to diesel fuel. And 37.7% smoke emission increases when B100 was compared to the diesel fuel at full loading condition.

References

[1] Z. Hajamini, M. A. Sobati, S. Shahhosseini, B. Ghobadian, "Waste fish oil (WFO) esterification catalyzed by sulfonated activated carbon under ultrasound irradiation" *Appl. Therm. Eng.*, Vol. 94, No. 1, pp.141–150, (2016).

[2] U. Rajak and T. N. Verma, "Effect of emission from ethylic biodiesel of edible and non-edible vegetable oil, animal fats, waste oil and alcohol in CI engine" *Energ. Convers. Manage.*, Vol. 166, No. 10, pp. 704–718, (2018).

[3] E. Jiaqiang, M. H. Pham, Y. Deng, T. Nguyen, V. N. Duy, D. H. Le, Z. Zhang, "Effects of injection timing and injection pressure on performance and exhaust emissions of a common rail diesel engine fueled by various concentrations of fish-oil biodiesel blends" *Energ.*, Vol. 149, No. 1, pp. 979–989, (2018).

[4] R. El-Araby, A. Amin, A. K.El Morsi, N. N. El-Ibiari, & G. I. El-Diwani, "Study on the characteristics of palm oil–biodiesel–diesel fuel blend" *Egyp. Jour. of Petro.*, Vol. 27, No. 2, pp. 187–194, (2018).

[5] R. Dhanasekaran, S. Ganesan, Rajesh Kumar, S. Saravanan, "Utilization of waste cooking oil in a light-duty DI diesel engine for cleaner emissions using bio-derived propanol" *Fuel*, Vol. 235, No. 1, pp. 832–837, (2019).

[6] S. H. Dhawane, T. Kumar, G. Halder, "Process optimisation and parametric effects on synthesis of lipase immobilised carbonaceous catalyst for conversion of rubber seed oil to biodiesel" *Energ. Convers. Manage.*, Vol. 176, No. 1, pp. 55–68, (2018).

[7] H. Hazar and H. Sevinc, "Investigation of the effects of pre-heated linseed oil on performance and exhaust emission at a coated diesel engine" *Renew. Energ.*, Vol. 130, pp. 961–967, (2019).

[8] B. Kathirvelu, S. Subramanian, N. Govindan, S. Santhanam, "Emission characteristics of biodiesel obtained from jatropha seeds and fish wastes in a diesel engine" *Sustain. Environ. Res.*, Vol. 27, No. 6, pp. 283–290, (2017).

[9] A. Mahalingam, Y. Devarajan, S. Radhakrishnan, S. Vellaiyan, B. Nagappan, "Emissions analysis on mahua oil biodiesel and higher alcohol blends in

diesel engine" *Alex. Eng. Jour.*, Vol. 1, No. 1, pp.3–7, (2017).

[10] M. S. M. Zaharin, N. R. Abdullah, G. Najafi, H. Sharudin, T. Yusaf, "Effects of physicochemical properties of biodiesel fuel blends with alcohol on diesel engine performance and exhaust emissions", *Renew. Sust. Energ. Rev.*, Vol. 79, No. 1, pp. 475–493, (2017).

[11] I. A. Adeoti, K. Hawboldt & M. R. Santos, "Thermal and flow properties of fish oil blends with bunker fuel oil" *Fuel*, Vol. 158, No. 1, pp. 641–649, (2015).

[12] K. Bhaskar, G. Nagarajan, S. Sampath, "Optimization of FOME (fish oil methyl esters) blend and EGR (exhaust gas recirculation) for simultaneous control of NOx and particulate matter emissions in diesel engines" *Energ*, Vol. 62, No. 1, pp. 224–234, (2013).

[13] R. Yahyaee, B. Ghobadian & G. Najafi, "Waste fish oil biodiesel as a source of renewable fuel in Iran" *Renew. Sust. Energ. Rev*, Vol. 17, No. 6, pp. 312–319, (2013).

[14] S. Gnanasekaran, N. Saravanan, and M. Ilangkumaran, "Influence of injection timing on performance, emission and combustion characteristics of a DI diesel engine running on fish oil biodiesel" *Energy*, Vol. 116, No. 1, pp. 1218–1229, (2016).

[15] G. Sakthivel, G. Nagarajan, M. Ilangkumaran, & A. B. Gaikwad, "Comparative analysis of performance, emission and combustion parameters of diesel engine fuelled with ethyl ester of fish oil and its diesel blends" *Fuel*, Vol. 132, No. 1, pp. 116–124, (2014).

[16] S. Ushakov, H. Valland, V. Aesoy, "Combustion and emissions characteristics of fish oil fuel in a heavy-duty diesel engine" *Energ. Convers. Manage.*, Vol. 65, No. 1, pp. 228–238, (2013).

[17] M. Saei Moghaddam & A. Zarringhalam Moghaddam, "Performance and exhaust emission characteristics of a CI engine fueled with diesel-nitrogenated additives" *Chem. Engg. Res. Design*, Vol. 92, No. 4, pp. 720–726, (2014).

[18] C. Y. Lin, and R. J. Li, "Engine performance and emission characteristics of marine fish-oil biodiesel produced from the discarded parts of marine fish" *Fuel Process. Tech.*, Vol. 90, No. 7–8, pp. 883–888, (2009).

[19] R. Behçet, "Performance and emission study of waste anchovy fish biodiesel in a diesel engine" *Fuel Process. Technol.*, Vol. 92, No. 6, pp. 1187–1194, (2011).

[20] A. Gharehghani, M. Mirsalim, & R. Hosseini, "Effects of waste fish oil biodiesel on diesel engine combustion characteristics and emission" *Renew. Energy*, Vol. 101, No. 1, pp. 930–936, (2017).

[21] S. Godiganur, C. Suryanarayana Murthy, R. P. Reddy, "Performance and emission characteristics of a Kirloskar HA394 diesel engine operated on fish oil methyl esters" *Renew. Energ*, Vol. 35, No. 1, pp. 355–359, (2010).

[22] U. Rajak, & T. N. Verma, "Spirulina microalgae biodiesel – A novel renewable alternative energy source for compression ignition engine" *J. Clean. Prod.*, Vol. 201, No.1, pp. 343–357, (2018).

[23] C. M. Sivaraja, and G. Sakthivel, "Compression ignition engine performance modelling using hybrid MCDM techniques for the selection of optimum fish oil biodiesel blend at different injection timings" *Energy.*, Vol. 139, No. 1, pp. 118–141, (2017).

[24] I. A. Adeoti, and K. Hawboldt, "A review of lipid extraction from fish processing by-product for use as a biofuel" *Biomass. Bioenergy*, Vol. 63, No. 1, pp. 330–340, (2014).

[25] N. Mrad, E. G. Varuvel, M. Tazerout, & F. Aloui, "Effects of biofuel from fish oil industrial residue - Diesel blends in diesel engine" *Energy*, Vol. 44, pp. 955–963, (2012).

[26] Upendra Rajak, Prerana Nashine, and Tikendra Nath Verma; "Experimental Study on Spray Characteristics of Biodiesel-Diesel Fuels Blends in a

Constant Volume Chamber", *J. Eng. Appl. Sci.* Vol. 5, No. 2, pp. 1-13, (2018).

[27] A. Hussana, I. Khan, M.R. Gorji, and W.A. Khan "CNT S – Water – Based Nanofluid over a Stretching Sheet", *Bio Nano sci.*, Vol. 9, No. 1, pp. 21-29, (2019).

[28] U. Rajak, P. Nashine & T. N. Verma "Assessment of diesel engine performance using spirulina microalgae biodiesel" *Energy.*, Vol. 166, pp. 1025-1036, (2018).

[29] U. Rajak, P. Nashine, T. N. Verma, "Comparative assessment of the emission characteristics of first, second and third generation biodiesels as fuel in a diesel engine" *J. Therm. Eng.*, Vol. 6, No. 6, pp. 211-225, (2020).

[30] Upendra Rajak, and Tikendra Nath Verma; "A comparative analysis of engine characteristics from various biodiesels: Numerical study", *Energ. Convers. Manage.*; Vol. 180, No. 1, p.p. 904-923, (2019).

[31] Thokchom Subhaschandra Singh, Tikendra Nath Verma; "Taguchi design approach for extraction of methyl ester from waste cooking oil using synthesized CaO as heterogeneous catalyst: Response surface methodology optimization", *Energy. Convers. Manage.;* Vol. 182, No. 1, pp. 383-397, (2019).

[32] Thokchom Subhaschandra Singh, Tikendra Nath Verma, Prerana Nashine; "Analysis of an anaerobic digester using numerical and experimental method for biogas production", *Mat. Tod.: Proce., Els.;* Vol. 5, No. 2P1, pp. 5202-5207, (2018).

[33] U Rajak, TN Verma. "Influence of emission characteristics using Microalgae biodiesel in diesel engine", *Inter. Res. Pub. Hous.*; *Computer Application in Education & Research for Science and Technology*, Chapter 20, pp. 221-230, (2019).

[34] Upendra Rajak, Prerana Nashine, Tikendra Nath Verma; Effect of Fuel Injection Pressure in a Diesel Engine using Microalgae-Diesel Emulsion; *Int. J. Eng. Adv. Technol.*, Vol 8, No. 3, pp 263-271, (2019).

[35] U. Rajak, T. N. Verma. "Influence of emission characteristics using Microalgae biodiesel in diesel engine", *Int. Res. Pub. Hous.*; Computer Application in Education & Research for Science and Technology, Chapter 20, pp. 221-230, (2019).

[36] Upendra Rajak, Tikendra Nath Verma; "Influence of combustion characteristics on a compression ignition engine from different generation of biofuels", *Eng. Sci. Technol., Int. J.*, Vol. 23, No. 1, pp. 10-20, (2020).

[37] U. Rajak, P. Nashine, T. S. Singh, and T. N. Verma, "Numerical investigation of performance, combustion and emission characteristics of various biofuels*". Energ. Convers. Manage.*, Vol. 156, pp. 235–252, (2018).

[38] T. S. Singh, T. N. Verma, P. Nashine, C. Shijagurumayum. "BS-III diesel vehicles in Imphal, India*", An emi. Pers. Spring. (Air pollu. & cont.);* chapter 5, pp. 73-86, (2018).

[39] T. S. Singh, N. S. Khundrakpam, P. Nashine, TN Verma**,** M Banerjee; "Performance analysis of a MFVCR engine in SI mode using variable loading conditions", *Intern. J. Ind. Eng. Manage. Sci.*, Vol. 6, No. 4, pp. 174-176, (2016).

[40] P. Shrivastava, T. N. Verma, "An experimental investigation into engine characteristics fuelled with lal ambari biodiesel and its blends" *Therm. Sci. Eng. Prog.* Vol. 17, p. 100356, (2020).

[41] T. S. Singh, T. N. Verma, P Nashine, C. Shijagurumayum. "BS-III diesel vehicles in Imphal, India*", An emission. Perspective. Spring.* (In Air pollution & control); chapter 5, pp. 73-86, (2018).

[42] T. S. Singh, T. N. Verma. "Impact of Tri-Fuel on compression ignition engine emissions: Blends of waste frying oil-alcohol-diesel" *Sprin. (Meth. and the Alt. Fuel Eco.);* Chapter 7, pp. 135-156, (2019).

[43] U. Rajak, P. Nashine, T. N. Verma, "Performance analysis and exhaust emissions of Aegle methyl ester operated compression ignition engine", *Therm. Sci. Eng. Prog.*, Vol. 12, (2019).

How to cite this paper:

Deepak Kumar Sharmaa and Tikendra Nath Verma,"Characteristics of fish oil biodiesel with the impact of diesel fuel addition on a CI engine" *J. Comput. Appl. Res. Mech. Eng.*, Vol. 10, No. 2, pp. 325-336, (2021).

DOI: 10.22061/jcarme.2019.4737.1571

URL: https://jcarme.sru.ac.ir/?_action=showPDF&article=1545