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INJECTION PRESSURE EFFECTS ON COMBUSTION, PERFORMANCE AND EMISSION OF A COMPRESSION IGNITION ENGINE WITH FISH OIL BIODIESEL USING TITANIUM AND ALUMINA NANOPARTICLE AS ADDITIVE

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Abstract

Present days conventional petroleum-based fuels are widely being used to operate IC engines, such fuels being non-renewable in nature are getting considerably depleted in a short period due to its incriminated use in various sectors. There arises the requisite of alternative fuels. Fish oil, which is an animal fat is known to be a hopeful backup to Diesel. In this study, fish oil methyl ester (fish oil biodiesel) was obtained by the transesterification process using methanol with the aid of potassium hydroxide as a catalyst. Properties of obtained biodiesel are tabulated according to ASTM standard, which is compatible with properties of conventional diesel fuel. The objective of the present work was the study of the consequence of injection pressure on the performance, combustion and emission characteristics of a diesel engine using B20 fish oil methyl esters. Experiments were carried out by varying injection pressure. Tests are carried out on a single cylinder, four strokes, water cooled and direct injection diesel engine. From the results, it is revealed that 200 bar injection pressure shows better results. In order to study the advantage of nanoparticles in terms of performance of the CI engine, in the present work alumina and titanium nanoparticles were added to B20 fish biodiesel. The experiments were conducted for rated load at 200 bar injection pressure. From the results, it was found that improvement in performance and combustion; and considerable reduction in NO_X and CO_2 emissions were observed as compared with B20 biodiesel and diesel as fuel in the same engine.

Keywords: Biodiesel, CI Engine, Fish Oil Methyl Ester, Titanium and alumina nanoparticles, Transesterification.

1. Introduction

The diesel engine has proven to be widely used in many sectors of society. Diesel engines have been a great aid in the field of transportation, industries and agriculture. Simple operation, easy maintenance and rugged construction are the attractive features of diesel engines. With the increasing demand of petroleum products, a bigger menace to the cleaner environment is being poised as the combustion of these fuel yields emissions like carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_X) and particulate matter, which is currently the main source of emissions globally. Air pollution and hence, environmental pollution is mainly caused due to these emissions. Most interested alternative fuels are those, which can be used with minimal or no alteration of existing engines [1]. Sustainability, energy security, and diversity, as well as greenhouse gas mitigation, are the reasons for the apace growing interest in biofuels. Biodiesel is a non-toxic, clean-burning, biodegradable combustible fuel derived from used or new animal fats or vegetable oils [2]. Biodiesel reduces global warming gas such as carbon dioxide (CO_2). Biodiesel is attracted because of its renewable and environmentally friendly nature as it is made from transesterification of seed-based oils, animal fats, and other biomass sources [1, 2]. Biodiesel due to its chemical nature of containing more compounds that are basically made up of oxygen as a key element in it results in lowering the emissions of CO, HC and particulate matter, which are the major hazardous by-product of combustion phenomena. Romm [3] and Attia et al. [4] explained that biodiesel also has a relatively supportive ignition ability than diesel due to greater cetane number.

The use of plant-based fuels has resulted in addressing social problems since growing of these plants will consume more cultivated land and fresh water resulting in the imbalance of the food chain due to the constant increase in the world population. Hence, to address these problems, this work is mainly focused on the alternative fuels derived from an aquatic resource such fish fat and also using different nanoparticles as additives for better combustion mechanism on which, minimal work has been reported. Fish oil is largely obtained in fish processing industries as a by-product. It is extracted from the waste generated, which depends on the mass of the species and the techniques of processing. Fish cultivation can be done even in saline water and it requires minimum land, which will reduce the burden of utilizing the agricultural land and fresh water for growing plants to achieve the required quantity of feedstock for producing alternative fuel for petroleum diesel [5].

Injection pressure has an important role in performance, combustion and emission characteristics. At low injection pressures, the ignition delay period increases. Acquiring a high degree of fuel atomization and sufficient evaporation of fuel in very short time needs high injection pressure in the fuel injection system. In the present study by Karabektas et al. [6] and Monyem and Van Gerpen [7], the injection pressure is varied from 180 to 220 bar. As increased NO_X and soot formation are the major disadvantages of using biofuels, several methods like the usage of fuel additives such as antioxidants and nanoparticles were used to minimize the NO_X emissions considerably [8].

Nanoparticles typically measure 1 to 100 nm in diameter. Nanoparticles have a high surface to volume ratio due to which, it promotes combustion by improved atomization. During combustion, the Nano alumina in suspension promotes the formation of micro-explosions, which assists proper air-fuel mixing, which in turn results in a cleaner and improved efficient combustion.

Alumina and Titanium nanoparticles were used as additives in biodiesel blends and it was observed that there was a considerable reduction in emissions and appreciable increase in Brake thermal efficiency. The titanium oxide nanoparticle plays an important role as an oxidation catalyst, which oxidizes CO and HC emissions during combustion. The specifications of the nanoparticles are shown in Table 1.

It is observed that nanoparticles are promising additives in order to counter the major disadvantages of bio-fuel usage [9]. Therefore, the use of fish oil methyl ester biodiesel with alumina and titanium oxide nanoparticle is presented in this paper. The properties of tested fuels are shown in Table 2.

Table 1. Specification of nanoparticles.

	Alumina	**Titanium**
Chemical name	**Gamma aluminum oxide (Alumina, Al_2O_3) Nano powder, gamma phase, 99.9%**	**Titanium (TiO_2) Nano Powder**
Average particle size	20-50 nm	21 nm
Appearance	White	White
Melting point	2045 ◦C	1843 ◦C
Boiling point	2980 ◦C	2972 ◦C
Density	3.9 g/cm^3	4.23 g/cm^3

Table 2. Properties of tested fuels.

Property/oil (easter)	**Diesel**	**Fish**		
		Oil	**Biodiesel**	**B20 Blend**
Kinematic viscosity cst 40◦C	3.08	24.31	3.777	3.19
Density, kg/m^3	828	898	878	837
Flash point, ◦c	60	194	160	80
Cetane number	40	48	80	80
Calorific value, MJ/kg	46	3608	38	44.4
Saponification value, mg/g	-	208.7	175.67	123.4
Iodine value ,mg/g	-	114	108	92
Acid number, mg.KOH/g	0.8	0.09	0.088	0.42
Water and sediment, % volume	0.08	0.106	0.008	0.041
Sulfated ash % mass	0.01	0.008	0.008	0.009
Carbon residue, % mass	0.38	0.124	0.078	0.29
Sulphur, % volume	0.08	0.021	0.009	0.041
Free fatty acid, % mass	-	1.37	0.97	-

1.1. Preparation of blend

B20FOME is obtained by taking 20% of biodiesel and 80% of diesel both percentages by volume and stirred constantly using magnetic stirrer for 20 to 25 minutes. B20FOMEAL and B20FOMETI were prepared by adding 30 mg of alumina nanoparticle and 30 mg of titanium nanoparticle per litre of B20 biodiesel blend respectively. The nanoparticles were dispersed into the required proportion of blend using 24 kHz frequency ultrasonicator. According to Demirbas, A et al. [10], the dispersion of nanoparticles in a base fluid is done by ultrasonication technique, which is a highly recommended method in order to prevent the agglomeration of nanoparticles.

1.2. Transesterification

Ramesha, D.K et al. [11] explained that the process of transesterification is as follows.

Sharma et al. [12] has also given similar explanation of transesterification process as depicted at molecular level as shown in Fig. 1.

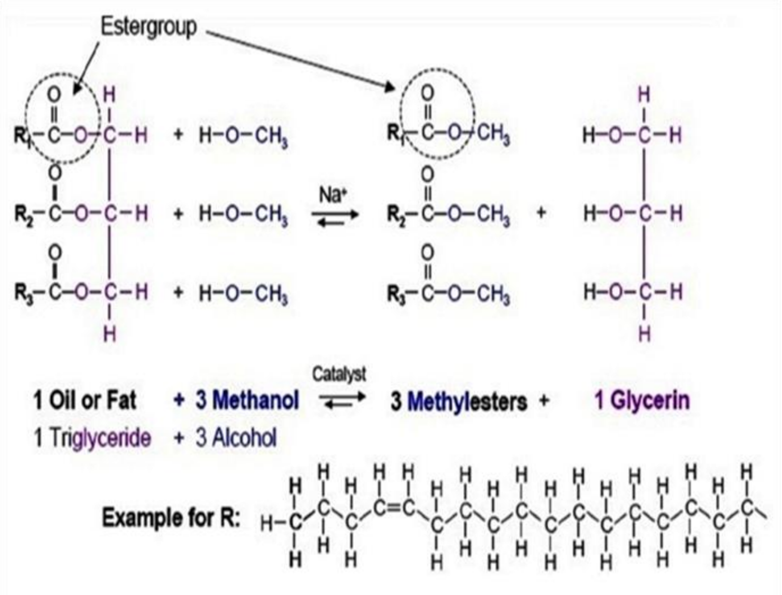

Fig. 1. Transesterification of fish oil [11].

2. Experimentation

Ramesh et al. [13] used a four-stroke diesel engine, which is considered in the present work.

The experiments were conducted at no-load, 25%, 50%, 75 % and 100% of full load condition operation at 180 bar injection pressure with B20FOME. The data such as airflow rate, fuel flow rate, NO_X, CO, and UBHC emissions, exhaust smoke opacity and exhaust temperature were recorded at this condition.

Similar experiments were conducted at 200 and 220 bar injector opening pressures (IP). For 200 bar optimised pressure alumina and titanium nanoparticles were added to the B20FOME and tested for the same above conditions.

For exhaust gas analysis, OROTECH Exhaust Gas analyser was used. The specifications of the analyser and smoke meter are shown in Tables 3 and 4 respectively.

Uncertainty analysis

Sequential perturbation was used to calculate the uncertainties of parameters and are listed in Table 3. The maximum values of the coefficient of variance of various parameters are listed in Table 4.

Table 3. Uncertainties percentage.

Parameters	Average uncertainties
Air flow rate	1.2%
LCV of fuel	1.0%
Engine speed	1.3%
Gas flow rate	2.1%
Engine load	0.2%
Liquid fuel flow rate	0.1%
Temperature	1.0%
Cylinder pressure	0.8%

Table 4. Maximum values of COV (Co-Efficient of Variance) of study parameters.

Parameters	Maximum COV
BTE	3%
BSFC	4%
Peak cylinder pressure	5%
Ignition delay	4%
CO emission	2%
HC emission	2%
NO_x emission	6%

3. Results and Discussion

3.1. Performance Analysis

3.1.1. Effect of injection pressure and blends on BTE

The comparison of BTE with load for B20FOME at different injection pressures and for different fuel additives at 200 bar injection pressure is shown in Figs. 2 and 3 respectively. It is known from the figures that there is an increase in BTE along with increasing load for all fuels.

This is the consequence of an increase in power and a reduction in heat loss. And also, it can be seen that the BTE is low at 180 bar injection pressure, which is lower. This can be the consequence of poor atomization and mixture of fuel and coarse spray formation during the injection. At 200 bar injection pressure, the BTE of B20FOME fuel has improved considerably.

This may be due to improved atomization and better combustion [14]. From the figure, it can also be observed that further increased injection pressure to 220 bar led to decrease in the BTE. The reason for this is, at higher injection pressure the size of fuel droplets decrease drastically [14, 15]. It can be noted that the highest value of BTE for the B20FOME tested is found to be at 200 bar injection pressure. It can be seen that at full load operation, the BTE of B20FOMEAL is 32 % and for B20FOMETI is 31% and that is nearest to diesel fuel 24%. The maximum increase in BTE with respect to diesel was shown by B20FOMEAL. The high surface area to volume ratio of nanoparticles, results in fine atomization along with rapid evaporation of fuel, which collectively contributes to increasing in BTE due to enhanced combustion of fuel.

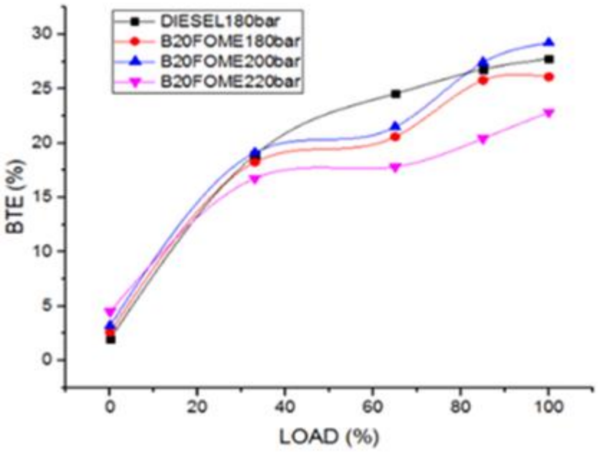

Fig. 2. Variation of BTE with load at varying injection pressure.

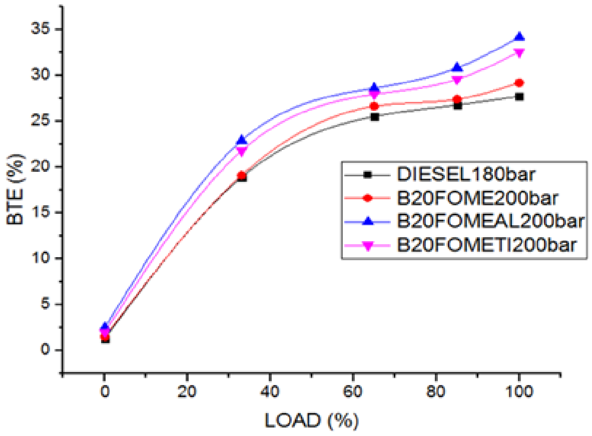

Fig. 3. Variation of BTE with load at 200 bar injection pressure.

3.1.2. Effect of injection pressure and blends on BSFC

The variation of BSFC (break specific fuel consumption) with load for different injection pressures for B20FOME and B20FOME with alumina and titanium nanoparticles at the better injection pressure of 200 bar is shown in Figs. 4 and 5 respectively. It can be seen from the figure that BSFC for B20FOME is marginally greater than diesel fuel at lower loads.

The higher values for biodiesel consumption as compared to diesel fuel may be the consequence of lower calorific value and higher viscosity of biofuels. However, at higher loads, the BSFC for B20FOME is less than the diesel fuel at 200bar. The lowest BSFC is obtained for B20FOMEAL and B20FOMETI compared to

B20FOME at 200 bar and at full load. This may be the result of nanoparticles addition to the biodiesel, which promotes the combustion process.

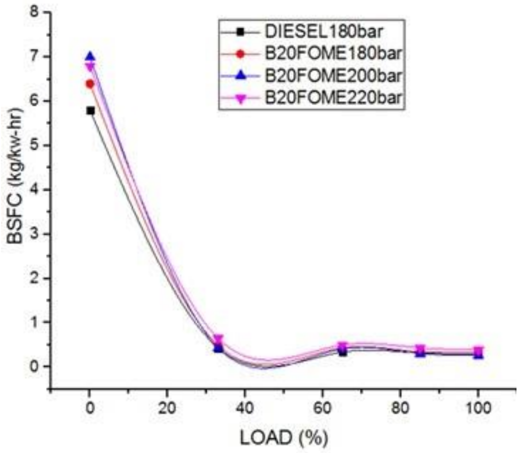

Fig. 4. Variation of BSFC with load at varying injection pressure.

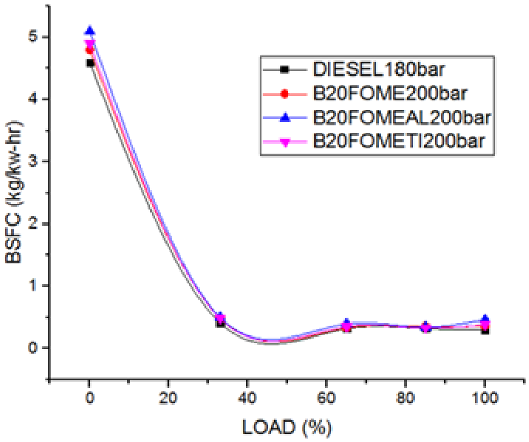

Fig. 5. Variation of BSFC with load at 200 bar injection pressure.

3.2. Combustion analysis

3.2.1. Effect of injection pressure and blends on heat release rate.

The comparison of HRR (heat release rate) with a crank angle for B20FOME with nanoparticles as an additive at a better injection pressure of 200 bar is as shown in Fig. 6. This graph depicts an assessable portrayal of fuel burning corresponding to time. Initially, during ignition delay as the fuel vaporises, negative HRR is observed and the same becomes positive in a later ignition period [16].

Heat is released rapidly at the beginning of ignition when the premixed air-fuel mixture starts to burn. It is observed that B20FOMEAL with 200 bar injection pressure shows greater HRR.

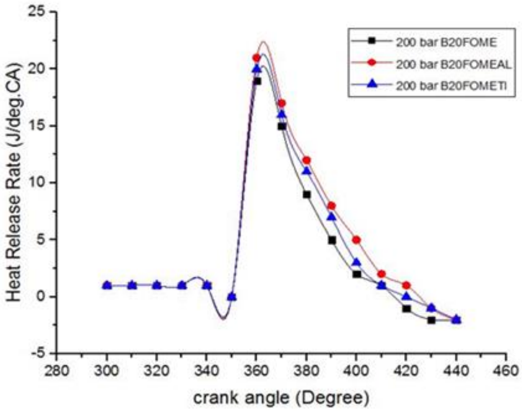

Fig. 6. Variation of HRR with CA at 200 bar injection pressure.

3.2.2. Effect of injection pressure and blends on cylinder pressure

Figure 7 shows the variation of cylinder pressure with a crank angle for B20FOME fuel added with alumina and titanium nanoparticles as an additive at an injection pressure of 200ba r. At the injection pressure of 200bar, there is a rise in peak pressure for B20FOMEAL compared to other fuels. This is due to higher heat release at this combination of injection pressure. The Range of injection pressure is almost in between that of B20FOME and B20FOMEAL for B20FOMETI.

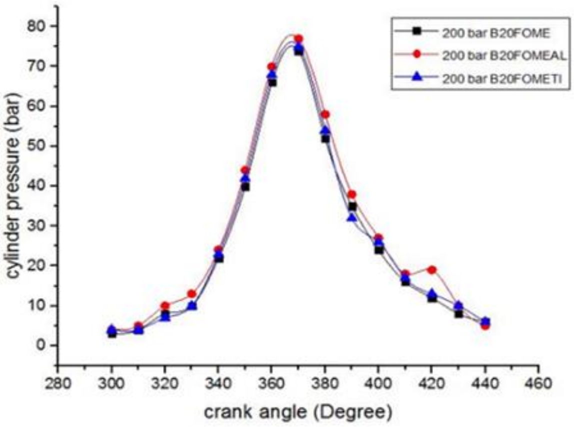

Fig. 7. Variation of CP with CA at 200 bar injection pressure.

3.3. Emission analysis

3.3.1. Effect of injection pressure and blends on unburnt hydrocarbon (UBHC)

Figures 8 and 9 show the variation of UBHC emission with load at different injection pressures for B20FOME and at different nano fuel additives for B20FOME fuel at a better injection pressure of 200 bar respectively. From it, we can see that the UBHC emissions have reduced at higher injection pressures of 200 bar from the rated pressure of 180 bar for B20FOME fuel. It can be inferred that as the injection pressure is further increased to 220 bar there seems to be an increase in UBHC emissions, which can be attributed to finer fuel spray, which results in less complete combustion due to decreased momentum of the droplets. From Fig. 8 it can be noted that the lowest value of UBHC emission for both fuels tested is found to be at 200 bar injection pressure than diesel fuel at all loads. The oxygen presence in biofuels is thought to promote complete combustion that gives lower UBHC emissions. An immense decrease in UBHC emission upon addition of alumina nanoparticle is observed due to beneficial properties of alumina such as its catalytic behaviour that promotes combustion, ability to minimise delay period and supporting the ignition process. UBHC emission is more in FOMETI than FOMEAL, availability of more oxygen in alumina than titanium is the reason behind this.

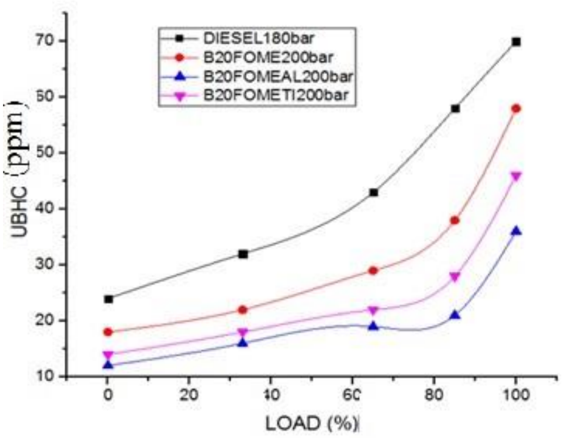

Fig. 8. Variation of UBHC with load at varying injection pressure.

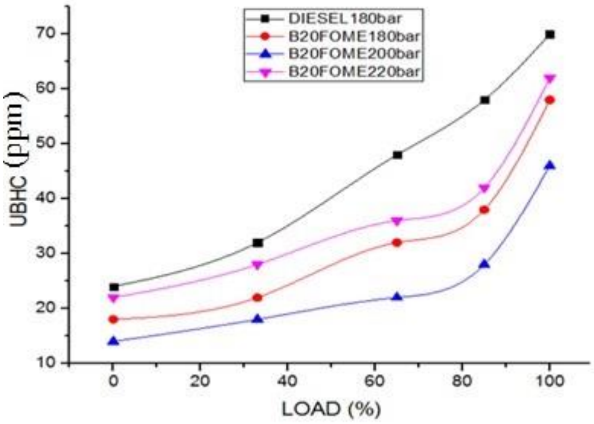

Fig. 9. Variation of UBHC with load at 200 bar injection pressure.

3.3.2. Effect of injection pressure and blends on carbon monoxide (CO)

The variation of CO emission with load at three different injection pressures and for different fuel additives for FOME at 200 bar injection pressure are shown in

Figures 10 and 11 respectively. As seen from figures, the CO emissions using diesel were higher than that of esterified oils under operating conditions.

From Fig. 8, it is evident that the CO emissions have reduced as injection pressure is increased to 200 bar from the rated injection pressure of 180 bar for B20FOME fuel. It is also clear that as there is further increase in injection pressure to 220 bar there seems to be an increasing trend in CO emissions, which may be because of less complete combustion resulting in higher unburnt hydrocarbons [17].

It can be noted that the lowest value of CO emission for B20FOME tested is found to be at 200-bar injection at all loads. Figures 10 and 11 show suppressed CO emissions at initial load and again increase in the same at full load condition for all tested blends due to the optimal air-fuel mixture at initial load and the graph shows an increasing trend as fuel consumption increases after initial loads. CO emission for B20FOME30AL is lower than the other two fuels, i.e., OME and B20FOMETI at 200 bar injection pressure. Alumina nanoparticles have more oxygen quantity than titanium oxide, this causes more CO formation in FOMETI than FOMEAL.

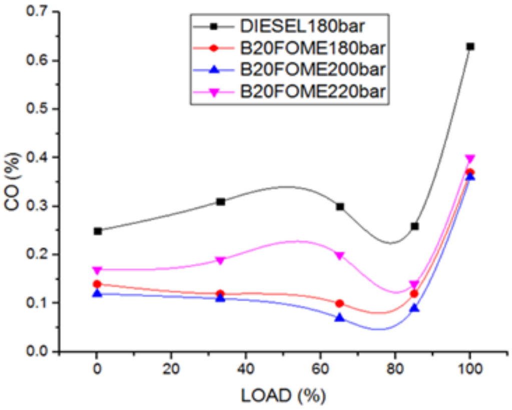

Fig. 10. Variation of CO with load at varying injection pressure.

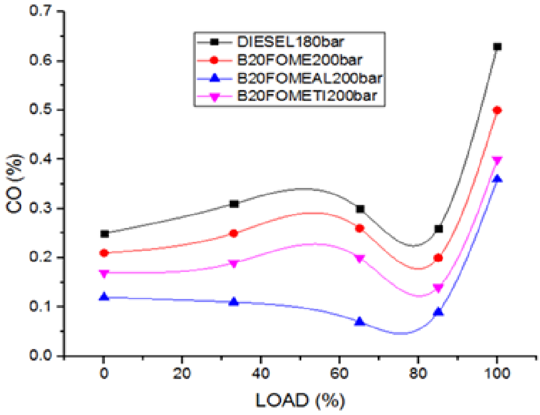

Fig. 11. Variation of CO with load at 200 bar injection pressure.

3.3.3. Effect of injection pressure and blends on oxides of nitrogen (NO_x)

The variation of NO_X emission with load at three different injection pressures and at different nano fuel additives for B20FOME at 200 bar injection pressure is shown in Figs. 12 and 13 respectively. It is observed that the NO_X emissions have increased with increase in load at all injection pressure.

It can be seen from Fig. 12 that NO_X emissions are lower at 200 bar injection pressure. Lower emission of NO_X at this injection pressure may be the consequence of the decrease in the engine exhaust temperature.

The higher emission of NO_X at injection pressures of 180 bar and 220 bar are the result of higher exhaust temperature [17, 18].

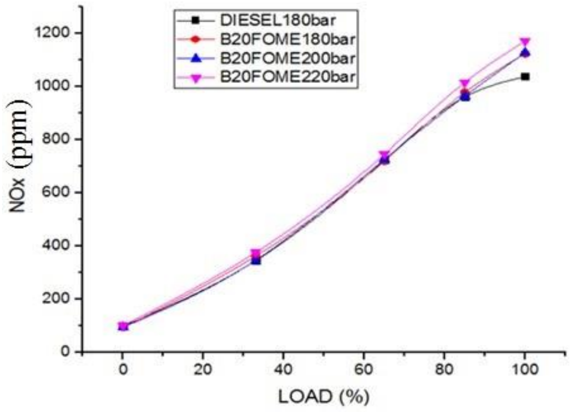

Fig. 12. Variation of NO_X with load at varying injection pressure.

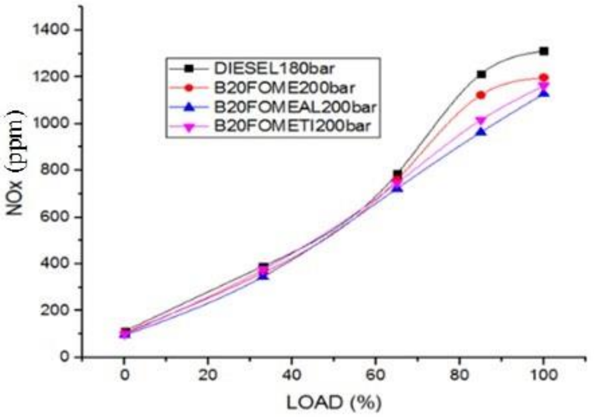

Fig. 13. Variation of NO_X with load at 200 bar injection pressure.

3.3.4. Effect of injection pressure and blends on smoke opacity

The variation of smoke opacity with load at different injection pressures and at different nano fuel additives for B20FOME at a better injection pressure of 200 bar is depicted in Figs. 14 and 15 respectively. As it is clear from Figs. 14 and 15 for the fuel tested, smoke opacity increases as the load increases. In addition, as the injection pressure increased from 180 bar to 200 bar at 100% load, 1% reduction in smoke opacity is observed for B20FOME fuel. Further, the higher opacity has been recorded at an injection pressure of 220 bar. Therefore, at 200 bar B20FOME has marginally lower opacity than that of B20FOME operating at 220 bar, this is the result of an absence of sulphur and presence of oxygen in biodiesel, which plays an important role for enhanced fuel combustion. It is clear from Fig. 15 that the additives to the biodiesel added at full load [18]. Smoke opacity increases with load due to more fuel being consumed. As a factor of high viscosity smoke opacity of blends is high as a result of poor mixing of fuel with air. B20FOMEAL has slightly higher smoke opacity than the other two since the fragments of B20FOMEAL being substantial results in the increased smoke opacity than FOMETI.

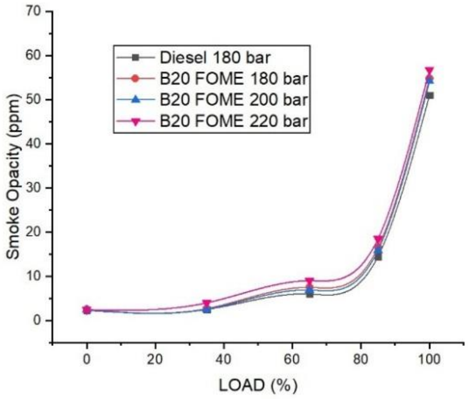

Fig. 14. Variation of smoke opacity with load at varying injection pressure.

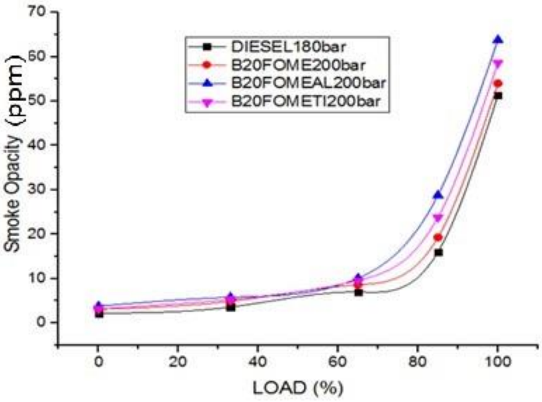

Fig. 15. Variation of smoke opacity with load at 200 bar injection pressure.

4. Conclusion

Methanol esterification method is adapted to convert fish oil into biodiesel, which converts free fatty acids into esters and reduces the viscosity of raw oil. Tests are conducted for injection pressures of 180 bar, 200 bar and 220 bar. Improved values of performance, emission and combustion characteristics are obtained at 200 bar injection pressure. The higher heat release rate and cylinder pressure are noticed for B20FOMEAL at 200 bar injection pressure. Dinesh et al. [18] reported that oxygen molecules in biodiesel promote better combustion characteristics. The emissions like UBHC, CO are comparatively lower for B20FOME blends with alumina and titanium nanoparticles compared to diesel for all injection pressures. Higher NO_X emissions were overcome by using titanium and aluminium nanoparticles as additives in biodiesel blends. In an agricultural dominated country like India with considerable cultivable lands experiencing frequent draughts, production of biodiesel from plants source can be avoided by the cultivation of high yielding fish using small ponds and seawater may significantly contribute to the energy security and green environment.

Nomenclatures

ASTM	American Society for Testing and Materials
BP	Brake Power
BTE	Brake Thermal Efficiency
HRR	Heat Release Rate
B20	20% Biodiesel and 80% Diesel
B20FOME	20% Fish oil Methyl Ester + 80% Diesel
B20FOMEAL	20% Fish oil Methyl Ester + 80% Diesel + 30mg/Lt Al2O3
B20FOMETI	20% Fish oil Methyl Ester + 80% Diesel + 30mg/Lt TiO2
BSFC	Brake Specific Fuel Consumption
BTDC	Before Top Dead Center
CA	Crank Angle
CI	Compression Ignition
CO	Carbon Monoxide
CP	Cylinder Pressure
FOME	Fish Oil Methyl Ester
NO_X	Oxides of Nitrogen
O_2	Oxygen
Ppm	Parts per Million
UBHC	Unburnt Hydrocarbon

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