



# Effect of Di-tert Butyl Peroxide on Diesel Engine Performance Fuelled by Biodiesel Blends

Pareshkumar K. Kachot <sup>a</sup>, D. K. Vyas <sup>b++</sup>  
and S. K. Chavda <sup>c#\*</sup>

<sup>a</sup> Department of Renewable Energy Engineering, CAET, Anand Agricultural University, Godhara, Gujarat, India.

<sup>b</sup> Department of Renewable Energy Engineering, CAET, AAU, Godhra, India.

<sup>c</sup> Department of Agriculture Engineering, CPCA, SDAU, S. K. Nagar, India.

## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

## Article Information

DOI: 10.9734/IJECC/2024/v14i13813

## Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/111646>

Original Research Article

Received: 01/11/2023

Accepted: 05/01/2024

Published: 05/01/2024

## ABSTRACT

This study is motivated by the fact that the vegetable oils are being considered as the fuel of the future for the internal combustion engines, especially the compression ignition engines which are working with diesel as fuel. Different approaches for using the vegetable oils in CI engines as fuel are either to modify the oils to match with that of diesel to run successfully with these oils. Fuel additives are compounds formulated to enhance the quality and efficiency of the fuels used in motor vehicles. There are several benefits associated with the use of fuel additives. Di-tert butyl peroxide (DTBP) is effective for enhance the quality and efficiency of the fuels used in CI engine. The investigation was to check the feasibility of di-tert butyl peroxide as an additive in different blends of diesel and jetropha bio-diesel on engine performance. The short-term tests on an unmodified diesel

<sup>++</sup> Head of Department;

<sup>#</sup> Assistant Professor;

<sup>\*</sup>Corresponding author: E-mail: skchavda16@gmail.com;

engine were conducted using the bio diesel and di-tert butyl peroxide blends (0, 10, 20, 30, 40, 50, and 100 per cent and 0, 0.5, 1.0, 1.5, 2.0, 2.5 per cent) with diesel. The engine performance and emission characteristics were measured during the short-term test. In all types of fuel, with increased percentage of load, brake specific energy consumption (BSEC) of the engine was observed to be decreased, on the other hand brake thermal efficiency, fuel consumption rate, sound level (db.), exhaust temperature, and the engine exhaust emissions like CO<sub>2</sub>, CO, HC and NO<sub>x</sub> was increased, respectively.

*Keywords: Bio diesel; transesterification; CI engine; Di-tert butyl peroxide.*

## 1. INTRODUCTION

Fuel and energy crisis and the concern of the society for the depleting world's non-renewable energy resources led to a renewed interest in the quest for alternative fuels. The increased industrialization and motorization of the world in recent years has resulted in great demand for petroleum products. Petroleum is the largest single source of energy, which has been consuming by the world's population, exceeding the other energy resources such as natural gas, coal, nuclear and renewable. The main consumers of energy are the electricity generation and transportation sectors. The diesel engine forms a vital part of both of these sectors throughout the world. Diesel fuel has versatile applications because of its high fuel efficiency compared to gasoline. Fuel crisis and environmental concerns have renewed interest of scientific community to look for alternative fuels of bio-origin such as vegetable oil. Bio-diesel was found as the best alternate fuel, technically and environmentally acceptable as well as easily available. Biodiesel consists of methyl/ethyl esters of fatty acids and is suitable for use in diesel engines [1].

General findings of almost all researchers are that CO, HC, SO<sub>x</sub> and particulate matters of engine emissions decreased with increasing proportion of bio-diesel in diesel-biodiesel mixture with some increase in emission of NO<sub>x</sub>. Presence of oxygen in bio-diesel is reported to be the reason for more complete combustion of carbon and hydrocarbon, while low sulfur content of biodiesel was responsible for reduction of SO<sub>x</sub> [2].

Rao et al. [3] investigated a single cylinder direct injection diesel engine using diesel-biodiesel blends with cetane improver Ethyl Hexyl Nitrate (EHN) as an additive under different Exhaust Gas Recirculation (EGR) conditions. The combined effect of EGR and Ethyl Hexyl Nitrate on Exhaust emissions was studied. With

increased in EGR percentage CO<sub>2</sub>, CO emissions increases while HC, NO<sub>x</sub> emissions decreases. Velmurugan and Gowthamn [4]. Tested a single cylinder direct injection diesel engine. Cetane improver additive of neopentane is used with the varying proportions of 1, 3 and 5ml to the diesel fuel respectively. Addition of cetane improver additive to the diesel fuel is cost effective way to control NO<sub>x</sub> emission. Diesel fuel with the 3ml additive of neopentane shows the significant reduction in NO<sub>x</sub> and smoke. The sensitivity of NO<sub>x</sub> to change in cetane number is higher at low load than at high load. It is found that NO<sub>x</sub> emissions were reduced at low load than at high load. Ferreira et al. (2013) tested a single cylinder diesel generator with blends of diesel, biodiesel and ethanol at 1800 rpm that powered a resistive electric panel for mechanical performance and emissions profile of a diesel engine. Four different fuels were tested: B5 (95% diesel, 5% biodiesel v/v), B50 (50% diesel, 50% biodiesel v/v), 92% B50+8% E (46% diesel, 46% biodiesel, 8% ethanol v/v). Other composition was tested with the use of a cetane improver (DTBP: di-tert butyl peroxide) in a ratio of 0.5% (91.54%B50+7.96%E+0.5%A). The compositions were prepared using the S-10 diesel oil and soybean biodiesel. The Tests occurred at low load conditions. Emissions profile, specific fuel consumption and energy analysis were evaluated. It was noticed a decreasing in energy efficiency, NO<sub>x</sub> and CO emissions with increase in ethanol content and increasing of NO<sub>x</sub> emissions with Biodiesel addition. The use of DTBP showed a slight increase in energy efficiency, but an increasing in NO<sub>x</sub> and CO emissions was noticed. Venkateswarlu et al. [5] studied and tested a single cylinder four stroke naturally aspirated direct injection air cooled diesel engine with exhaust gas recirculation and cetane improver Di Tertiary Butyl Peroxide (DTBP) as an additive to diesel-biodiesel blends. The combined effect of EGR and DTBP on Brake Thermal Efficiency(BTE), Brake Specific Fuel Consumption (BSFC), cylinder pressure and exhaust emissions is studied. Based on the

experimental results it is found that an EGR percentage of around 15% results in maximum BTE and minimum BSFC. It is also found that the combined effect of EGR and cetane improver reduces the NO<sub>x</sub> emissions by 25% with a slight increase in Carbon Monoxide (CO), Hydro Carbon (HC) and smoke opacity. Patel and Singh [6] studied and conducted on single cylinder four stroke diesel engines using blended soya methyl ester (B50) to optimize the NO<sub>x</sub> emission with the addition of DTBP cetane improver. The engine was first run on petroleum diesel (B0), followed by B50 and combination of B50 and DTBP. A number of combinations, 50% biodiesel (B50) and 50% petroleum diesel along with di-tert butyl peroxide (DTBP) such as B50/D0.5, B50/D1.0, B50/D1.5, B50/D2.0, B50/D2.5 and B50/D3, were used in this study. For each test, engine performance and emission were measured. The addition of cetane improver could reduce the NO<sub>x</sub> emission significantly with the penalty of Brake Specific Fuel Consumption (BSFC), CO and unburned hydrocarbon. The addition of DTBP by volumes of 0.5, 1, 1.5, 2, 2.5 and 3% to B50, the NO<sub>x</sub> reduction was found as 3.57, 5.0, 5.0, 4.29, 4.88 and 4.9%, respectively as compared to B50 without additive. It was also noted that CO and SO<sub>x</sub> reduce up to 25% and 33.33%, respectively, compared with petroleum diesel when 1% of DTBP is used. Considering the emission parameters, and the cost of the additive, 1% DTBP would give the optimum results for NO<sub>x</sub> reduction. Krishnamoorthi and Natarajan [7] studied and evaluated the effects of diethyl ether as additive with waste fried oil/diesel blend on the performance and emissions of a direct injection diesel engine. The waste fried oil and diesel blending with diethyl ether (DEE) in the ratio of 0:100:0, 20:80:0, 30:70:0, 40:60:0, 15:80:5, 25:70:5 and 35:60:5 by volume were tested in CI Engine. The results show that compared with neat diesel, there is slightly lower brake specific fuel consumption (BSFC) for diesel waste fried oil and DEE blend. Strong reduction in emission is observed with diesel-bio waste fried oil and DEE at various engine loads. Waste fried oil at 25% and DEE 5% blend with diesel gave best performance in terms of low smoke intensity, emissions of HC, CO, CO<sub>2</sub> and NO<sub>x</sub>. Vadivela et al. [7] conducted and studied the effects of using diethyl ether as an additive to biodiesel/diesel blend on the performance and emission of a direct injection diesel engine. The mahua/mustard biodiesel and diesel are blended with diethyl ether (DEE) in the ratio of 0:100:0, 20:80:0, 30:70:0, 40:60:0, 15:80:5, 25:70:5 and 35:60:5 by volume and tested in CI Engine. The

results obtained were compared with neat diesel, there was slightly lower brake specific fuel consumption for diesel, biodiesel and DEE blend. Strong reduction in emissions was observed with diesel, biodiesel and DEE at various engine loads. Methyl ester of mustard biodiesel at 25% and DEE 5% blend with 70% diesel gave best performance in terms of low smoke intensity and emissions characteristics. Raj and Karthikayan [8] investigated and studied the effect of Di-tert butyl peroxide (DTBP) as additive on the performance, exhaust emissions and combustion characteristics of a single cylinder direct injection compression ignition engine fuelled with papaya seed oil methyl ester (PSME). Base data was generated on a 5.2 kW single-cylinder diesel engine with standard diesel fuel. PSME-diesel blends ranging from 25 to 100% of PSME with diesel fuel by volume were prepared and tested in the diesel engine without and with the addition of DTBP. Improved performance reduced NO<sub>x</sub> emissions with slight increase in smoke density and HC emissions were observed for PSME blends with additive than those for PSME blends without additive. Earlier heat release and increase in cylinder pressure were also observed for blends with additive.

## 2. MATERIALS AND METHODS

### 2.1 Production of Bio-diesel

Fresh oil was extracted from *Jatropha Curcas* seed using a mini oil expeller. Bio-diesel of *Jatropha Curcas* oil was prepared as per the procedure recommended by Gupta, 1984. Various steps involved in this procedure are shown in Fig. 1. Moisture free methanol was used in the methanol oil molar ratio of 6:1 (for 100 ml oil, 20 ml methanol and sodium hydroxide (1% by weight of oil) was used as catalyst. A homogenous mixture of methanol and sodium hydroxide was made.

The method basically involved five steps:

- i. Heating of oil 60°C (oil temperature kept below the boiling point of methanol i.e. 65°C).
- ii. Mixing of heated oil and alkaline methanol. The mixing was done in a stainless steel container, as stainless steel is inert to the corrosive action of sodium hydroxide and to the action of organic solvent methanol.
- iii. Separation of glycerol (which settles at the bottom) and fatty acid methyl esters.
- iv. Decanting of prepared ester and its washings with water (3-4 times) to remove

any impurities left. Separation of ester from water by 2<sup>nd</sup> decantation.

- v. Heating of decanted ester to remove all the traces of moisture.

## 2.2 Fuel Characterization of Bio-diesel and its Blends

Characterization of diesel and biodiesel was done at Department of Renewable Energy Engineering, Anand Agricultural University, Godhra, as per the ASTM standards (ASTM-1983). The following characteristics were determined for the said fuel.

1. Kinematic viscosity
2. Density
3. Flash and fire point
4. Cloud and pour point
5. Calorific value

Methods used for determination of different characteristics of fuels are as per standard.

## 2.3 Experimental set-up

An experimental setup was prepared in the Biofuel laboratory of Department of Renewable Energy Engineering, CAET, AAU, Godhra. The set up was comprising of one single cylinder engine with 5 kW load resistance for power measurement device, exhaust gas temperature sensors fitted at exhaust of the engine, sound level meter and digital microprocessor based exhaust gas analyzer and NO<sub>x</sub> analyzer. A Swati make (TV1/SV1), single cylinder, four stroke, water-cooled diesel engine having 16.5:1 compression ratio was selected for the study. CO and HC.

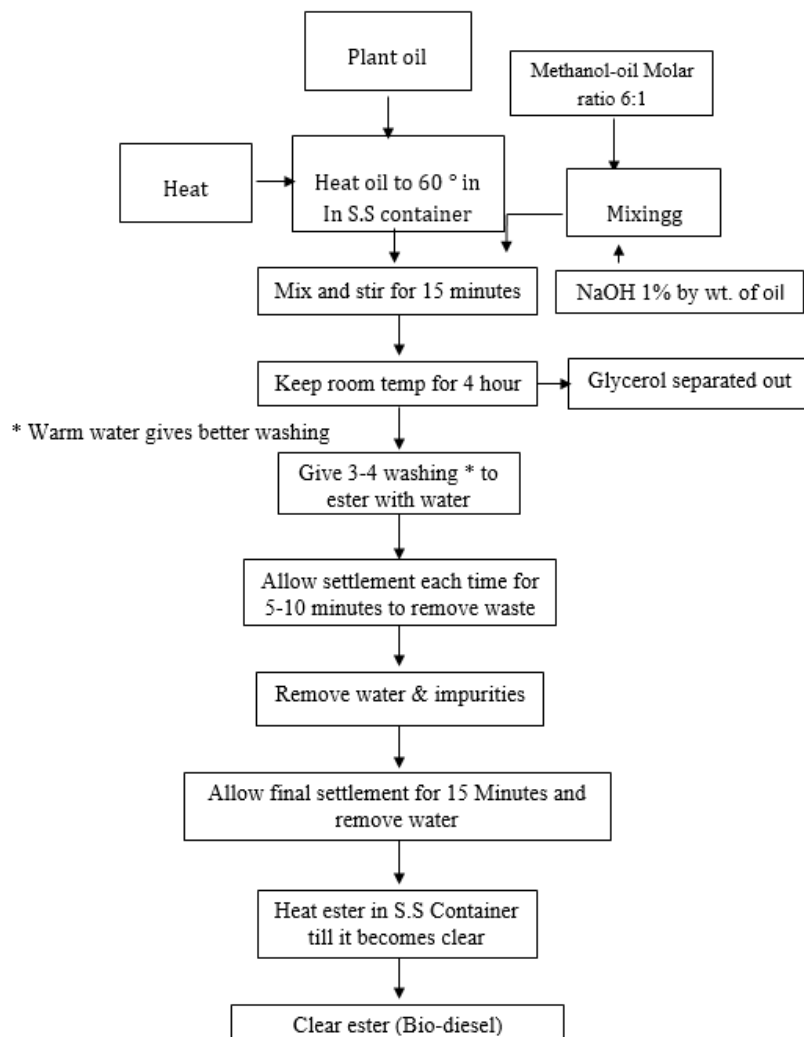


Chart 1. Simplified procedure for batch level esterification of plant oils

Blends were prepared by mixing Jatropha methyl ester with diesel in proportion of 10,20,30,40,50 and 100 percent on volume basis. The proportion of blend was identified by B10, B20, B30, B40, B50 and B100 where they stand for 10,20,30,40,50 and 100 percent ester with 90,80,70,60,50 and 0 percent diesel on volume basis respectively and were finally designated as B10, B20, B30, B40, B50, B100 and D100. In all, the fuels under test were seven in number along with diesel as control designated as D100.

The equipped sub systems in the engine set up were:

- i) Engine coupled to a generating set.
- ii) Fuel supply and measuring unit.
- iii) Electrical loading device.
- iv) Power measuring unit.

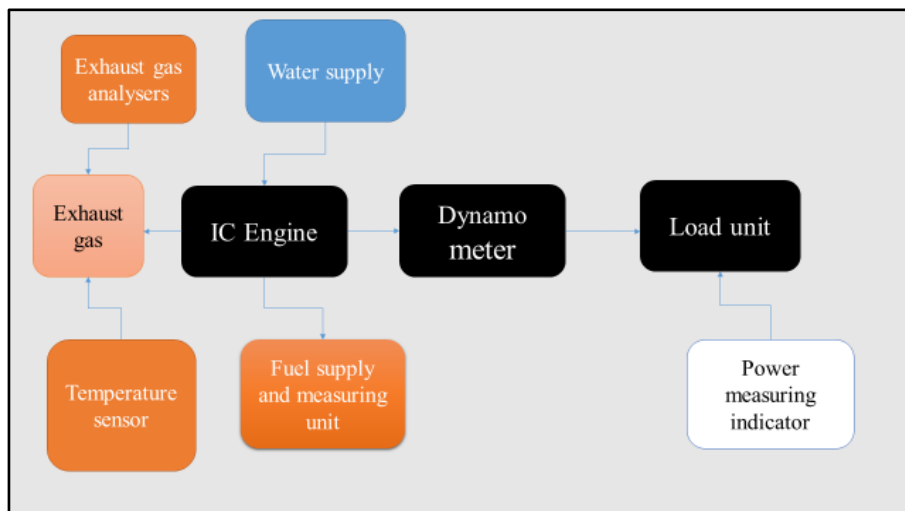


Chart 2. Schematic diagram of experimental set up

## 2.4 Exhaust Gas Analyzers

Three types of exhaust gas analyser is used for measuring concentration of different exhaust gas components.

- 1) Gas board analyser
- 2) NO<sub>x</sub> gas analyser
- 3) ECO GAS 100 gas analyser



Pic. 1. Gas board analyser



Pic. 2. NO<sub>x</sub> gas analyser



Pic. 3. ECO GAS 100 gas analyser

## 2.5 Engine Power Performance

### a) Power developed by engine

$$\text{Power in kW} = (V \times I)/1000$$

Where,

V = Voltage (Volt)

I = Current (Ampere)

### b) Break specific fuel consumption (BSFC)

Total Fuel Consumption TFC

$$\text{TFC} = (v \times \tau \times 3600)/t$$

Where,

TFC = Total fuel consumption, g/h

v = Volume of fuel, ml

$\tau$  = Specific gravity of the fuel,

t = Time taken to consume specific volume of fuel, sec

### c) Brake specific energy consumption (BSEC)

Break specific fuel consumption = Total fuel consumption / Power output,

$$\text{BSFC} = (\text{TFC}/P) \text{ (kg/kWh)}$$

### d) Brake thermal efficiency (BTE)

$$\eta_{bt}(\%) = \frac{\text{Energy equivalent of brake power (Kw)}}{\text{Energy supplied by fuel (Kw)}} \times 100$$

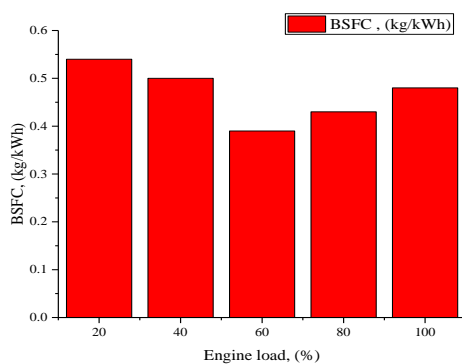


Fig. 1. Variation in brake specific fuel consumption of engine with different engine loads using 100 % diesel

Dharmadhikari [9]

## 3. RESULTS AND DISCUSSION

This is the analysis and representation of the experimental data collected during the course investigation.

The short duration engine performance test was conducted using diesel (100%) fuel for comparison with blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of di-tert butyl peroxide (DTBP) (0.5, 1.0, 1.5, 2.0 and 2.5%) at various engine load conditions (0, 20, 40, 60, 80 and 100 %) [10-14].

### 3.1 Performance of CI Engine with Different Loads, Different Blends of Biodiesel with Diesel Fuel and Different Proportions of DTBP Additive

#### i. Brake specific fuel consumption

Brake specific fuel consumption designated as BSFC is the quantity of fuel consumed per kilowatt per hour in an engine. Brake specific fuel consumption of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the Brake specific fuel consumption of the CI engine [15-20].

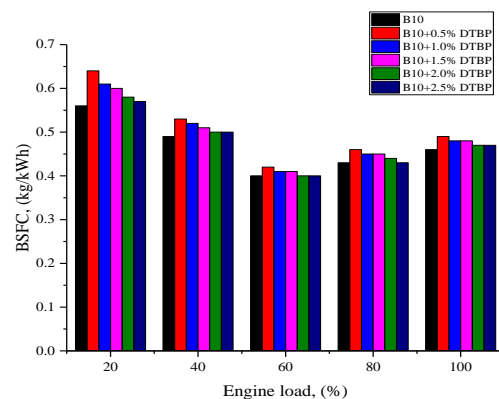


Fig. 2. Variation in brake specific fuel consumption of engine with different engine loads using B10 with different proportion of DTBP

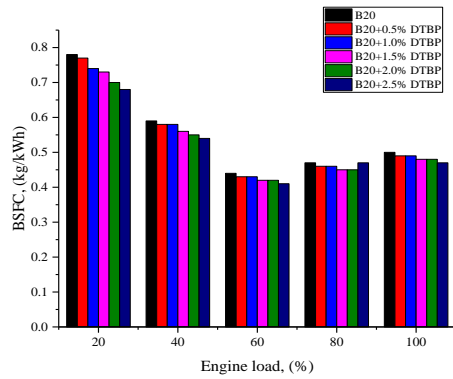


Fig. 3. Variation in brake specific fuel consumption of engine with different engine loads using B20 with different proportion of DTBP

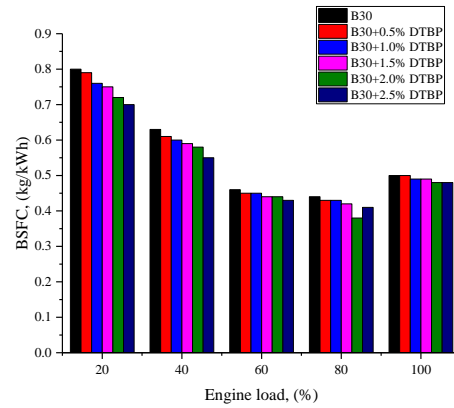


Fig. 4. Variation in brake specific fuel consumption of engine with different engine loads using B30 with different proportion of DTBP

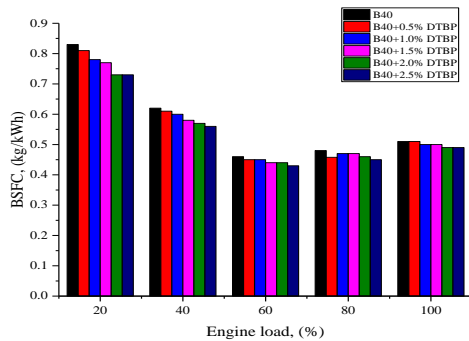


Fig. 5. Variation in brake specific fuel consumption of engine with different engine loads using B40 with different proportion of DTBP

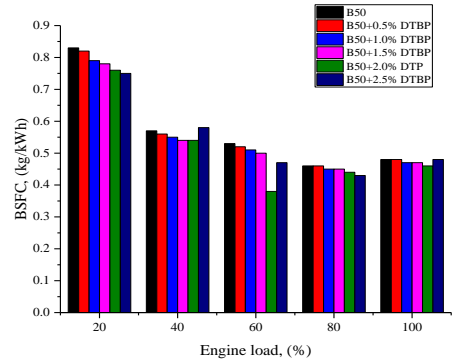


Fig. 6. Variation in brake specific fuel consumption of engine with different engine loads using B50 with different proportion of DTBP

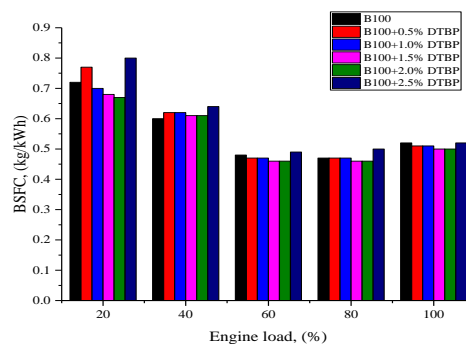


Fig. 7. Variation in brake specific fuel consumption of engine with different engine loads using B100 with different proportion of DTBP

The variation in brake specific fuel consumption at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%) at various load conditions (0, 20, 40,

60, 80 and 100 %) is shown in Fig. 1 to Fig. 7. The maximum and minimum in brake specific fuel consumption was observed 0.84 kg/kWh with B<sub>5</sub>A<sub>1</sub>L<sub>1</sub> and 0.37 kg/kWh with B<sub>3</sub>A<sub>5</sub>L<sub>5</sub> treatment combination respectively.

ii. Brake specific energy consumption

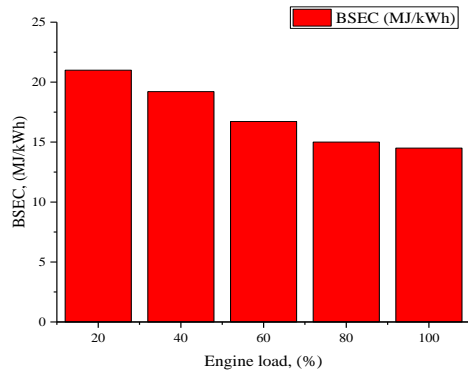


Fig. 8. Variation in brake specific energy consumption of engine with different engine loads using 100 % diesel

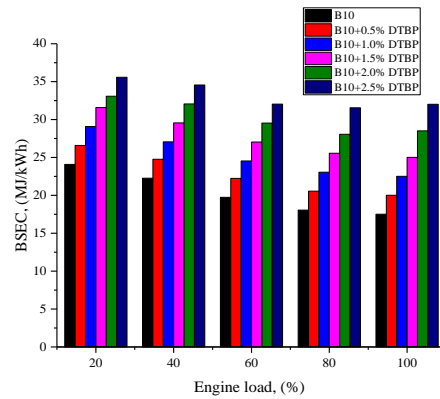


Fig. 9. Variation in brake specific energy consumption of engine with different engine loads using B10 with different proportion of DTBP

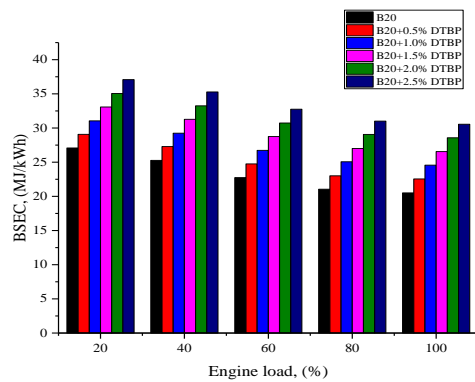


Fig. 10. Variation in brake specific energy consumption of engine with different engine loads using B20 with different proportion of DTBP

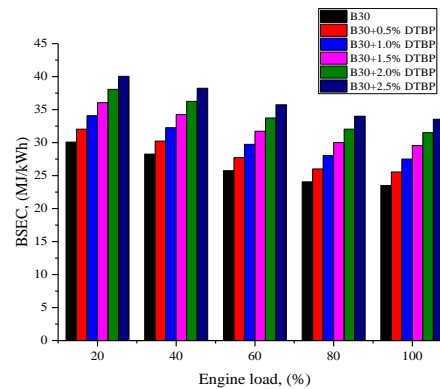


Fig. 11. Variation in brake specific energy consumption of engine with different engine loads using B30 with different proportion of DTBP

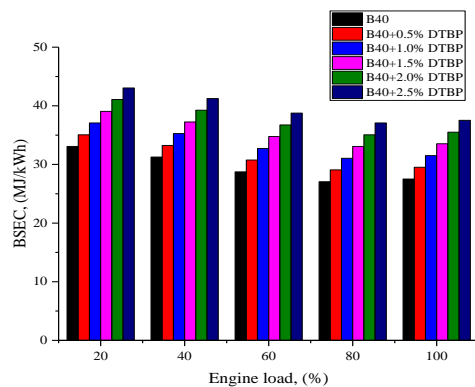


Fig. 12. Variation in brake specific energy consumption of engine with different engine loads using B40 with different proportion of DTBP

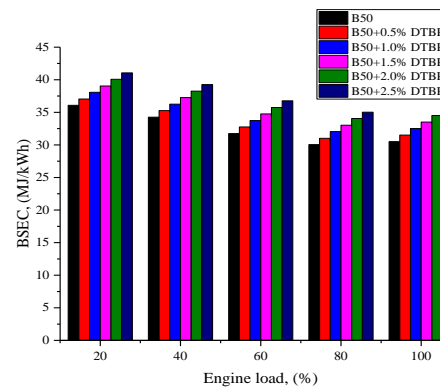


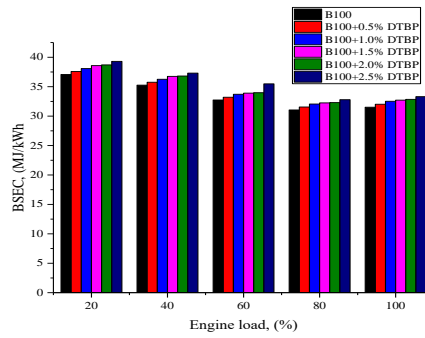
Fig. 13. Variation in brake specific energy consumption of engine with different engine loads using B50 with different proportion of DTBP

++ Head of Department;

# Assistant Professor;

\*Corresponding author: E-mail: skchavda16@gmail.com;



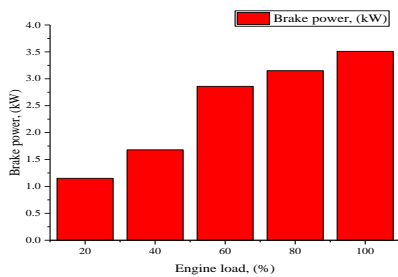


**Fig. 14** Variation in brake specific energy consumption of engine with different engine loads using B100 with different proportion of DTBP

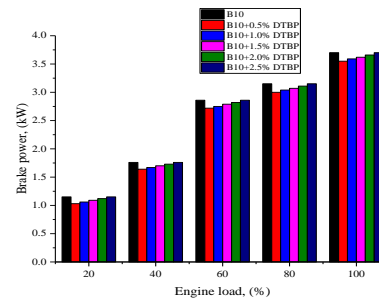
Brake specific energy consumption designated as BSFC is the quantity of energy consumed per kilowatt per hour in an engine. Brake specific energy consumption of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the Brake specific fuel consumption of the CI engine.

The variation in brake specific energy consumption at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%) at various load conditions (0, 20, 40, 60, 80 and 100 %) is shown in Fig. 8 to Fig. 14. The maximum and minimum in brake specific fuel consumption was observed 42.15 MJ/kWh with B<sub>4</sub>A<sub>6</sub>L<sub>2</sub> and 17.51 MJ/kWh with B<sub>1</sub>A<sub>1</sub>L<sub>6</sub> treatment combination respectively [21-25].

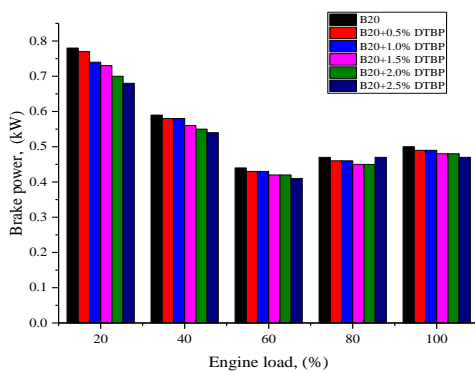
**iii. Brake power**



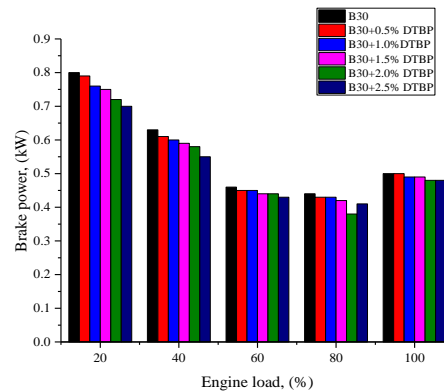
**Fig. 15** Variation in brake power (kW) of engine with different engine loads using 100 % diesel



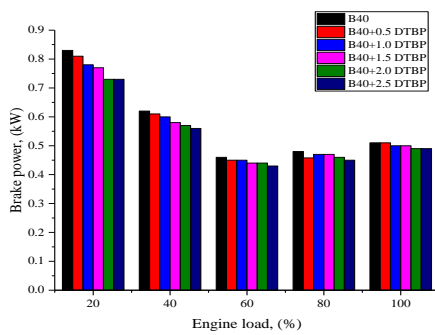
**Fig. 16** Variation in brake power (kW) of engine with different engine loads using B10 with different proportion of DTBP



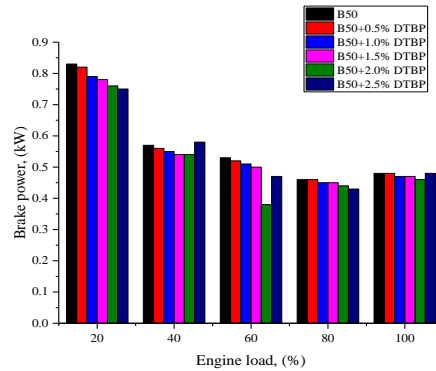
**Fig. 17** Variation in brake power (kW) of engine with different engine loads using B20 with different proportion of DTBP



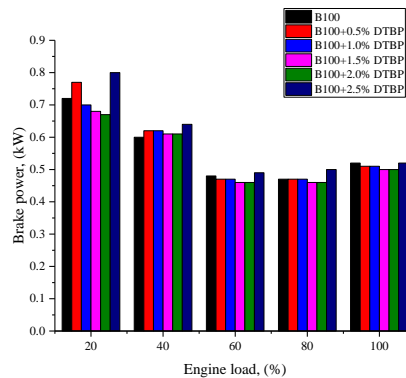
**Fig. 18** Variation in brake power (kW) of engine with different engine loads using B30 with different proportion of DTBP



**Fig. 19** Variation in brake power (kW) of engine with different engine loads using B40 with different proportion of DTBP



**Fig. 20** Variation in brake power (kW) of engine with different engine loads using B50 with different proportion of DTBP



**Fig. 21** Variation in brake power (kW) of engine with different engine loads using B100 with different proportion of DTBP

Brake power (kW) of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the Brake power of the CI engine [26,27].

The variation in brake power at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%) at various load conditions (0, 20, 40, 60, 80 and 100 %) is shown in Figs. 15 to Figs. 21. The maximum and minimum in brake power (kW) was observed 3.97 kW with B<sub>6</sub>A<sub>5</sub>L<sub>6</sub> and 0.85 kW with B<sub>4</sub>A<sub>1</sub>L<sub>2</sub> treatment combination respectively.

#### iv. Brake thermal efficiency

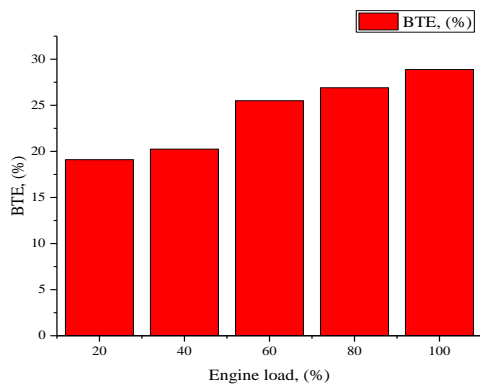
Brake thermal efficiency (%) of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the Brake thermal efficiency (%) of the CI engine.

The variation in brake power at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%) at various load conditions (0, 20, 40, 60, 80 and 100%) is shown in Fig. 22 to Fig. 28. The maximum and minimum in brake thermal efficiency (%) was observed 30.55 % with B<sub>1</sub>A<sub>6</sub>L<sub>6</sub> and 10.97% with B<sub>26</sub>A<sub>1</sub>L<sub>2</sub> treatment combination respectively.

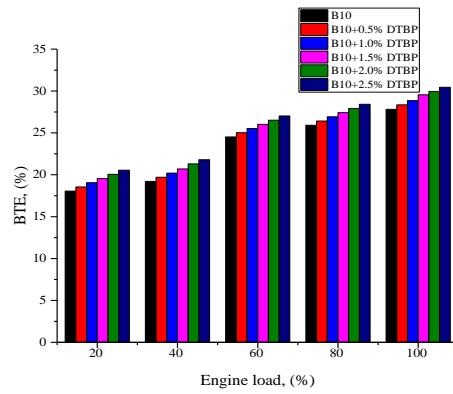
### 3.2 Emission Characteristics CI Engine with Different Loads, Different Blends of Biodiesel with Diesel Fuel and Different Proportions of DTBP Additive

#### a) Carbon dioxide (CO<sub>2</sub>)

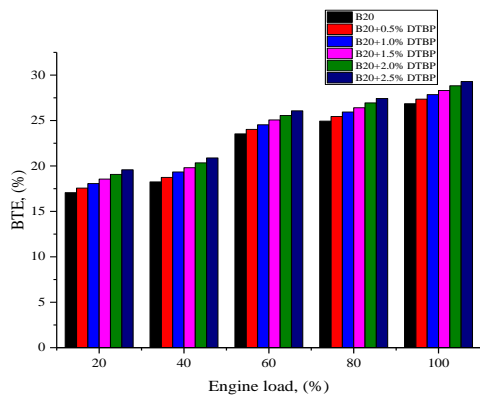
Carbon dioxide (CO<sub>2</sub>) (%) of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the Carbon dioxide (CO<sub>2</sub>) (%) of the CI engine.



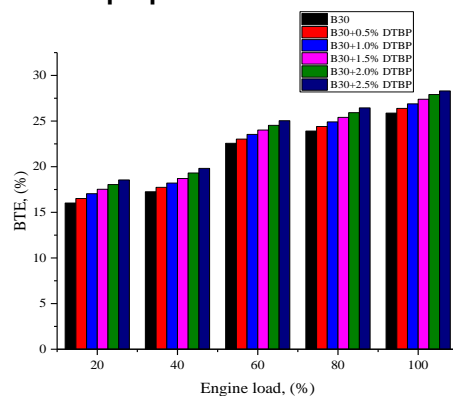
**Fig. 22.** Variation in brake thermal efficiency (%) of engine with different engine loads using 100 % diesel



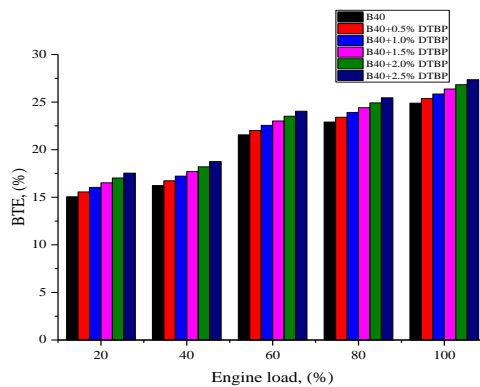
**Fig. 23.** Variation in brake thermal efficiency (%) of engine with different engine loads using B10 with different proportion of DTBP



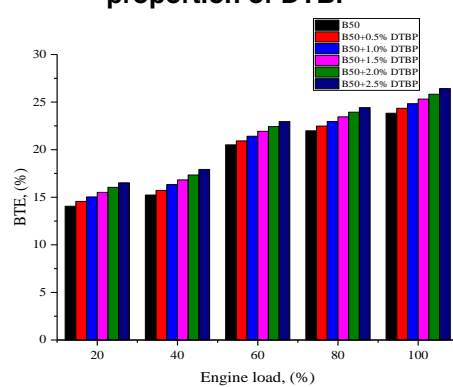
**Fig. 24.** Variation in brake thermal efficiency (%) of engine with different engine loads using B20 with different proportion of DTBP



**Fig. 25.** Variation in brake thermal efficiency (%) of engine with different engine loads using B30 with different proportion of DTBP



**Fig. 26.** Variation in brake thermal efficiency (%) of engine with different engine loads using B40 with different proportion of DTBP



**Fig. 27.** Variation in brake thermal efficiency (%) of engine with different engine loads using B50 with different proportion of DTBP

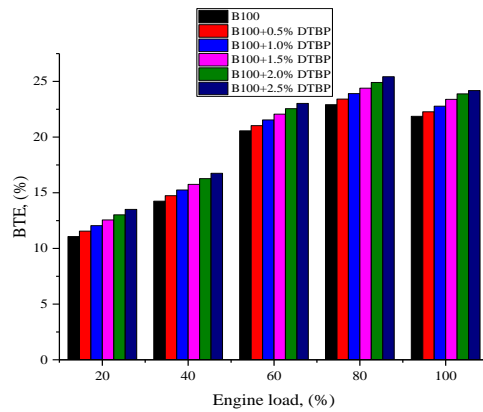


Fig. 28. Variation in brake thermal efficiency (%) of engine with different engine loads using B100 with different proportion of DTBP

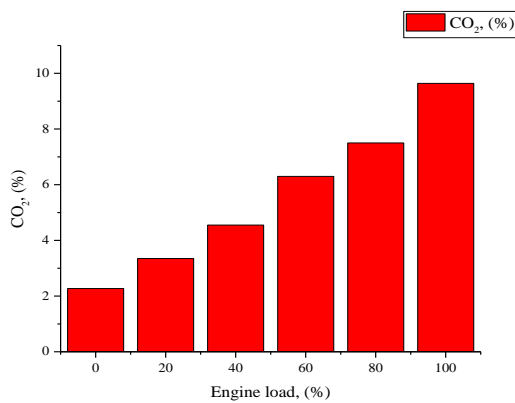


Fig. 29. Variation in carbon dioxide (CO<sub>2</sub>) (%) of engine with different engine loads using 100 % diesel

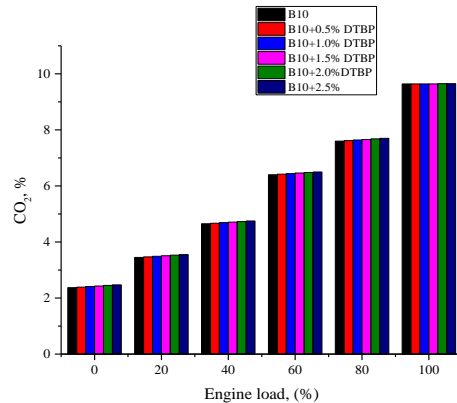


Fig. 30. Variation in carbon dioxide (CO<sub>2</sub>) (%) of engine with different engine loads using B10 with different proportion of DTBP

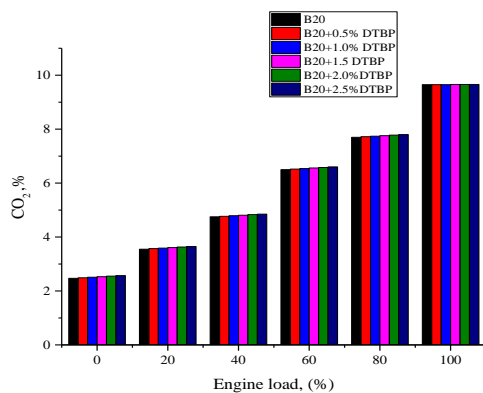


Fig. 31. Variation in carbon dioxide (CO<sub>2</sub>) (%) of engine with different engine loads using B20 with different proportion of DTBP

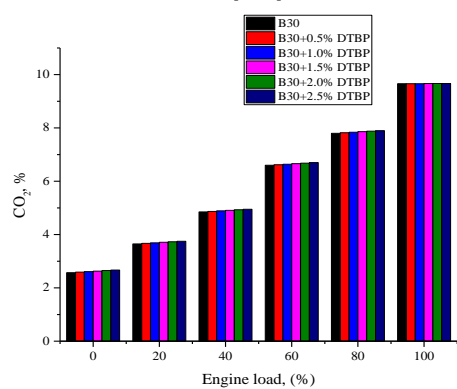
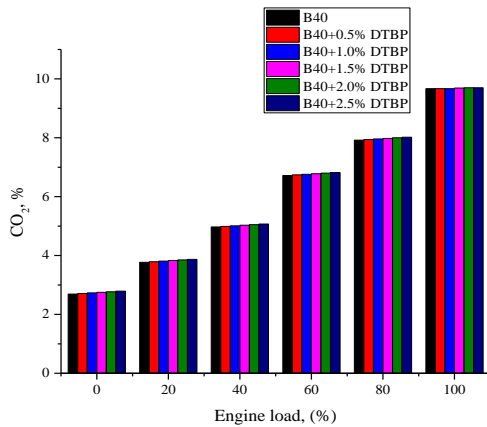
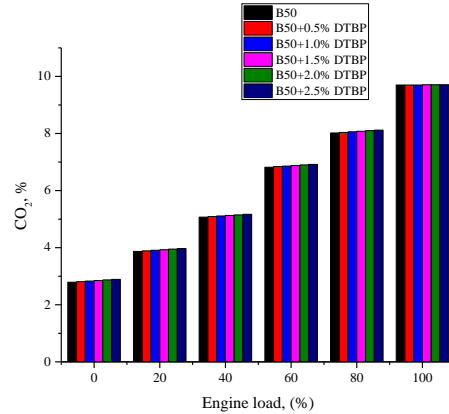


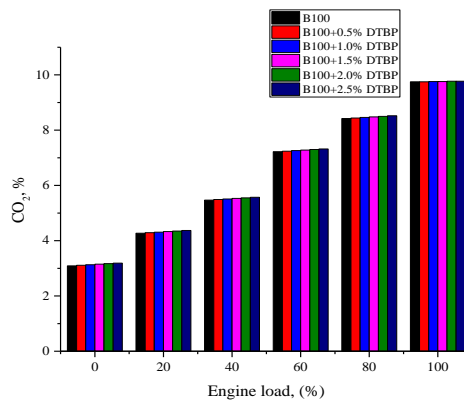
Fig. 32. Variation in carbon dioxide (CO<sub>2</sub>) (%) of engine with different engine loads using B30 with different proportion of DTBP



**Fig. 33. Variation in carbon dioxide (CO<sub>2</sub>) (%) of engine with different engine loads using B40 with different proportion of DTBP**



**Fig. 34. Variation in carbon dioxide (CO<sub>2</sub>) (%) of engine with different engine loads using B50 with different proportion of DTBP**



**Fig. 35. Variation in carbon dioxide (CO<sub>2</sub>) (%) of engine with different engine loads using B100 with different proportion of DTBP**

The variation in Carbon dioxide (CO<sub>2</sub>) at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%) at various load conditions (0, 20, 40, 60, 80 and 100 %) is shown in Fig. 29 to Fig. 35. The maximum and minimum in Carbon dioxide (CO<sub>2</sub>) (%) was observed 9.8 % with B<sub>6</sub>A<sub>6</sub>L<sub>6</sub> and 2.2 % with B<sub>5</sub>A<sub>6</sub>L<sub>3</sub> treatment combination respectively.

### b) Carbon monoxide (CO)

Carbon monoxide (CO) (%) of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the Carbon dioxide (CO<sub>2</sub>) (%) of the CI engine.

The variation in carbon monoxide (CO) (%) at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different

proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%) at various load conditions (0, 20, 40, 60, 80 and 100%) is shown in Fig. 36 to Fig. 42. The maximum and minimum in carbon monoxide (CO) (%) was observed 0.107 % with B<sub>1</sub>A<sub>1</sub>L<sub>6</sub> and 0.046 % with B<sub>6</sub>A<sub>6</sub>L<sub>1</sub> treatment combination respectively. Carbon monoxide (CO) emission permissible limit is 0.0687 %.

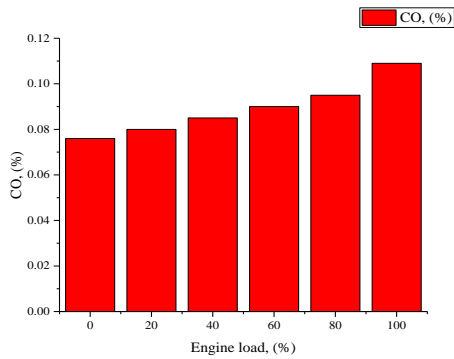
### c) Nitrogen oxides (NO<sub>x</sub>)

Nitrogen oxides (NO<sub>x</sub>) (ppm) of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the nitrogen oxides (NO<sub>x</sub>) (ppm) of the CI engine.

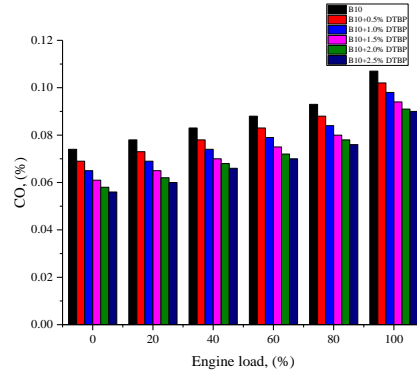
The variation in nitrogen oxides (NO<sub>x</sub>) (ppm) at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%)

at various load conditions (0, 20, 40, 60, 80 and 100 %) is shown in Fig. 43 to Fig. 49. The maximum and minimum in nitrogen oxides (NO<sub>x</sub>) (ppm) was observed 1325 ppm with B<sub>6</sub>A<sub>6</sub>L<sub>6</sub> and

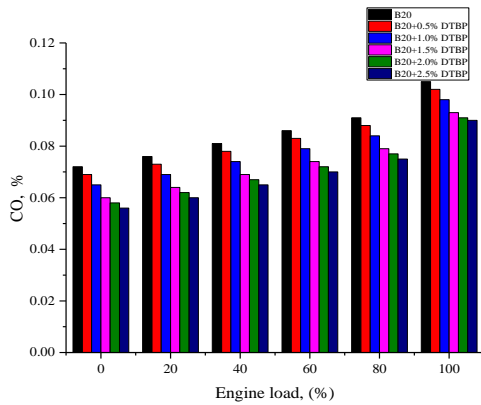
171 ppm with B<sub>1</sub>A<sub>3</sub>L<sub>1</sub> treatment combination respectively. Nitrogen oxides (NO<sub>x</sub>) permissible limit is 1011 ppm



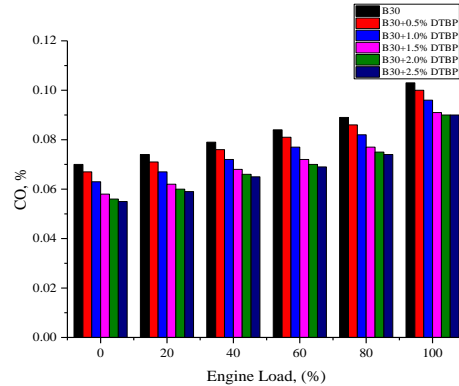
**Fig. 36.** Variation in carbon monoxide (CO) (%) emission of engine with different engine loads using 100 % diesel



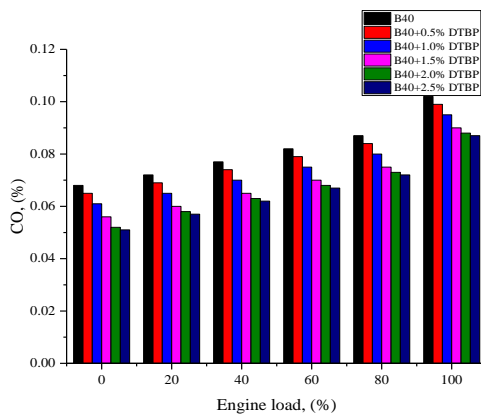
**Fig. 37.** Variation in carbon monoxide (CO) (%) emission of engine with different engine loads using B10 with different proportion of DTBP



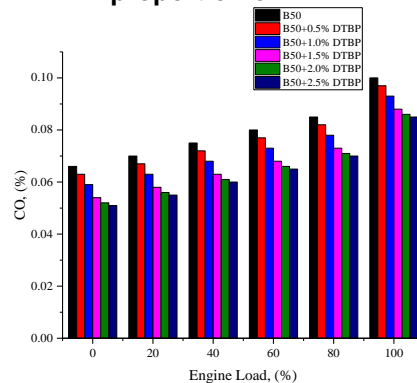
**Fig. 38.** Variation in carbon monoxide (CO) (%) emission of engine with different engine loads using B20 with different proportion of DTBP



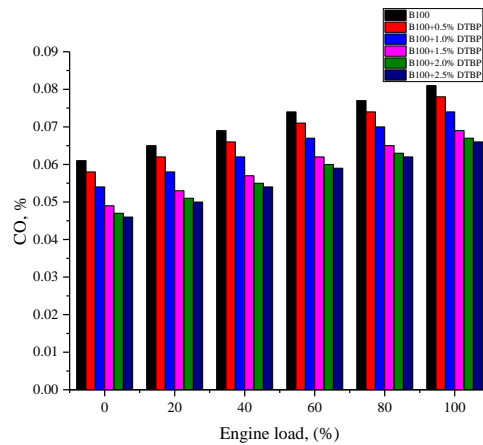
**Fig. 39.** Variation in carbon monoxide (CO) (%) emission of engine with different engine loads using B30 with different proportion of DTBP



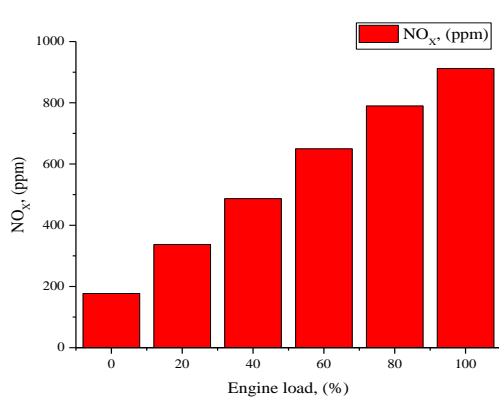
**Fig. 40.** Variation in carbon monoxide (CO) (%) emission of engine with different engine loads using B40 with different proportion of DTBP



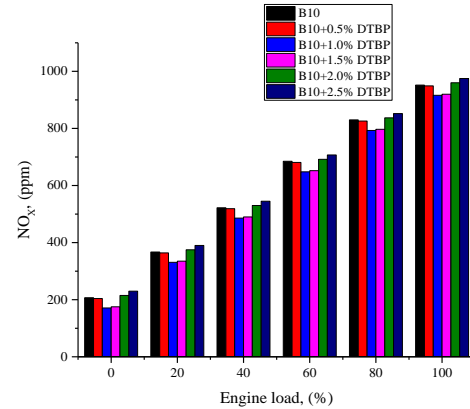
**Fig. 41.** Variation in carbon monoxide (CO) (%) emission of engine with different engine loads using B50 with different proportion of DTBP



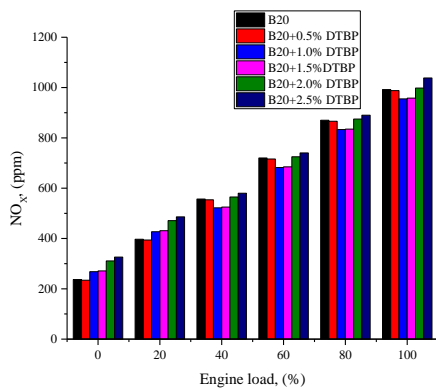
**Fig. 42.** Variation in carbon monoxide (CO) (%) emission of engine with different engine loads using B100 with different proportion of DTBP



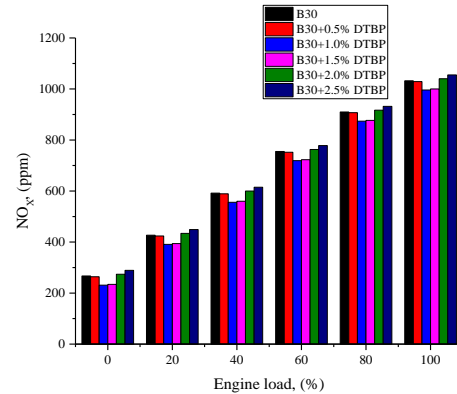
**Fig. 43.** Variation in nitrogen oxides (NO<sub>x</sub>) (ppm) emission of engine with different engine loads using 100 % diesel.



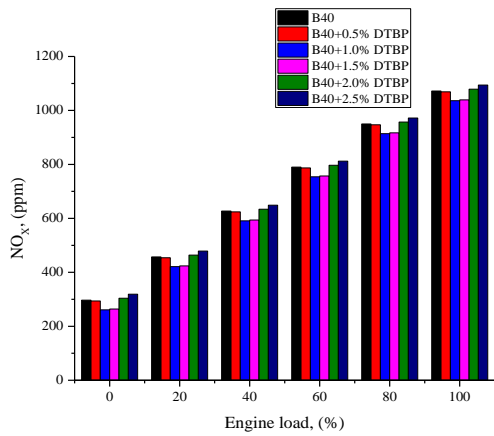
**Fig. 44.** Variation in nitrogen oxides (NO<sub>x</sub>) (ppm) emission of engine with different engine loads using B10 with different proportion of DTBP



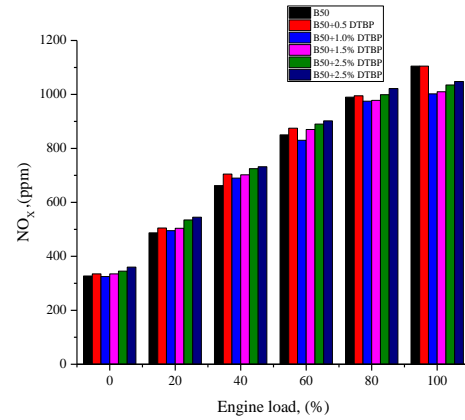
**Fig. 45.** Variation in nitrogen oxides (NO<sub>x</sub>) (ppm) emission of engine with different engine loads using B20 with different proportion of DTBP



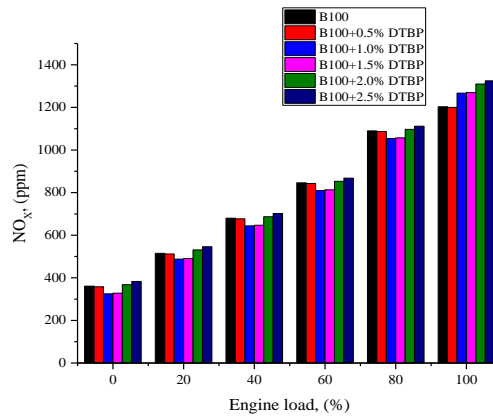
**Fig. 46.** Variation in nitrogen oxides (NO<sub>x</sub>) (ppm) emission of engine with different engine loads using B30 with different proportion of DTBP



**Fig. 47. Variation in nitrogen oxides (NO<sub>x</sub>) (ppm) emission of engine with different engine loads using B40 with different proportion of DTBP**

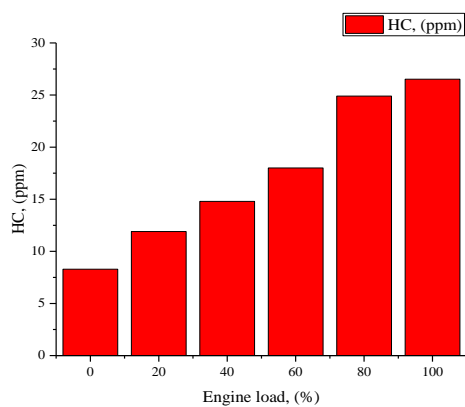


**Fig. 48. Variation in nitrogen oxides (NO<sub>x</sub>) (ppm) emission of engine with different engine loads using B50 with different proportion of DTBP**

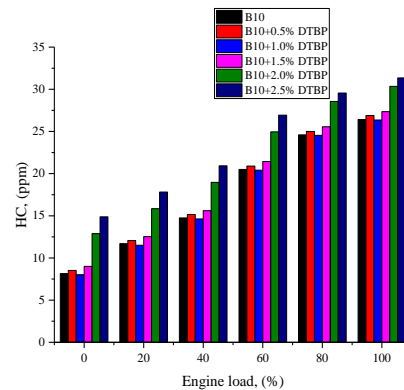


**Fig. 49. Variation in nitrogen oxides (NO<sub>x</sub>) (ppm) emission of engine with different engine loads using B100 with different proportion of DTBP**

**d) Hydrocarbons (HC)**

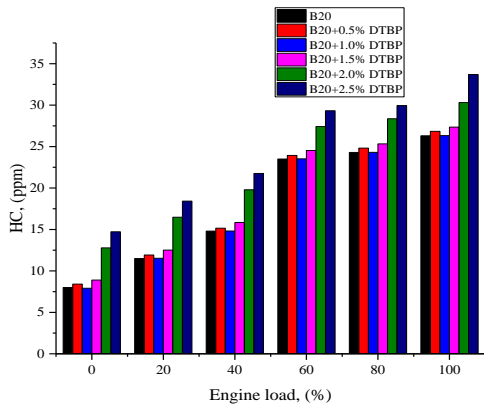


**Fig. 50. Variation in hydrocarbons (HC) (ppm) emission of engine with different engine loads using 100% diesel**

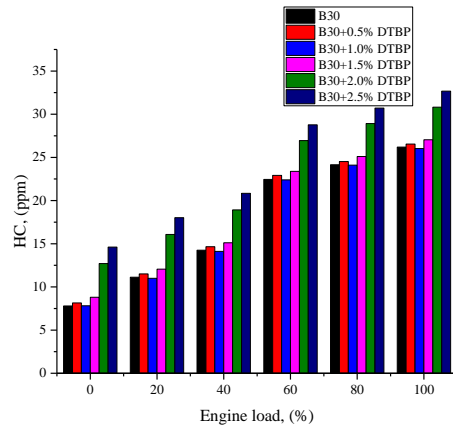


**Fig. 51. Variation in hydrocarbons (HC) (ppm) emission of engine with different engine loads using B10 with different proportion of DTBP**

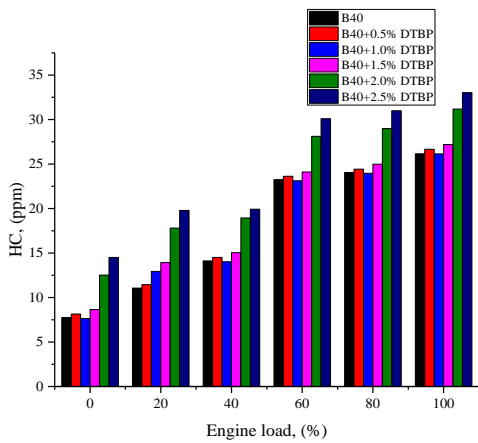




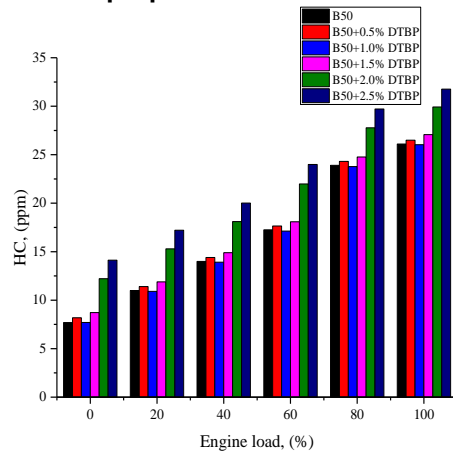
**Fig. 52. Variation in hydrocarbons (HC) (ppm) emission of engine with different engine loads using B20 with different proportion of DTBP**



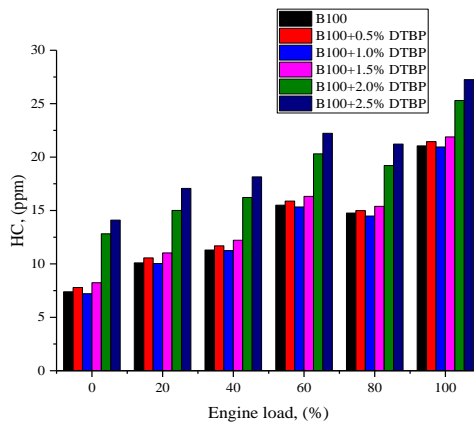
**Fig. 53. Variation in hydrocarbons (HC) (ppm) emission of engine with different engine loads using B30 with different proportion of DTBP**



**Fig. 54. Variation in hydrocarbons (HC) (ppm) emission of engine with different engine loads using B40 with different proportion of DTBP**



**Fig. 55. Variation in hydrocarbons (HC) (ppm) emission of engine with different engine loads using B50 with different proportion of DTBP**



**Fig. 56. Variation in hydrocarbons (HC) (ppm) emission of engine with different engine loads using B100 with different proportion of DTBP**

Hydrocarbons (HC) (ppm) of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the hydrocarbons (HC) (ppm) of the CI engine.

The variation in hydrocarbons (HC) (ppm) at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%) at various load conditions (0, 20, 40, 60, 80 and 100 %) is shown in Fig. 50 to Fig. 56. The maximum and minimum in hydrocarbons (HC) (ppm) was observed 33.69 ppm with B<sub>2</sub>A<sub>6</sub>L<sub>6</sub> and 7.21 ppm with B<sub>6</sub>A<sub>3</sub>L<sub>1</sub> treatment combination respectively. Hydrocarbons (HC) permissible limit is 480 ppm.

### e) Exhaust gas temperature

Exhaust gas temperature (°C) of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the exhaust gas temperature (°C) of the CI engine.

The variation in exhaust gas temperature (°C) at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%) at various load conditions (0, 20, 40, 60, 80 and 100 %) is shown in Fig. 57 to Fig. 63. The maximum and minimum in exhaust gas temperature (°C) was observed 546.53 °C with B<sub>1</sub>A<sub>6</sub>L<sub>6</sub> and 146.32 °C with B<sub>6</sub>A<sub>6</sub>L<sub>6</sub> treatment combination respectively.

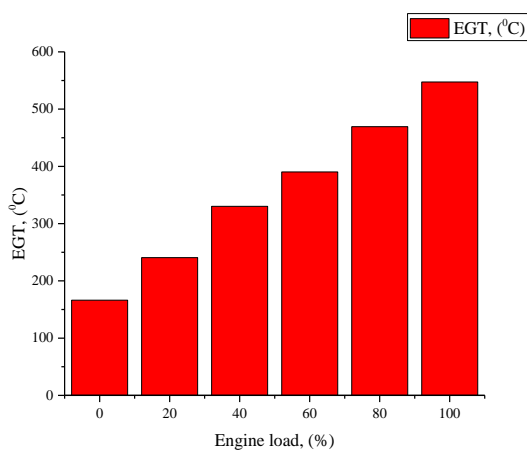


Fig. 57. Variation in exhaust gas temperature (°C) of engine with different engine loads using 100 % diesel.

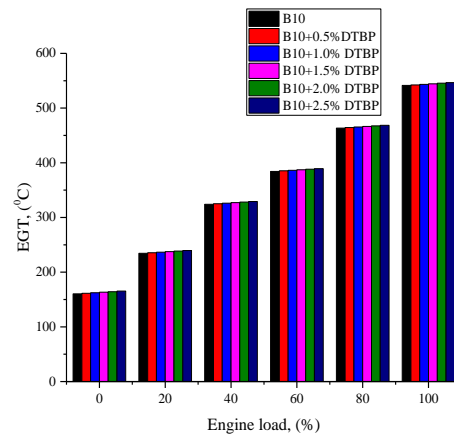


Fig. 58. Variation in exhaust gas temperature (°C) of engine with different engine loads using B10 with different proportion of DTBP

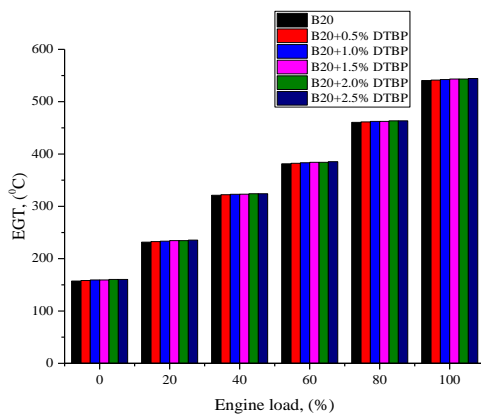


Fig. 59. Variation in exhaust gas temperature (°C) of engine with different engine loads using B20 with different proportion of DTBP

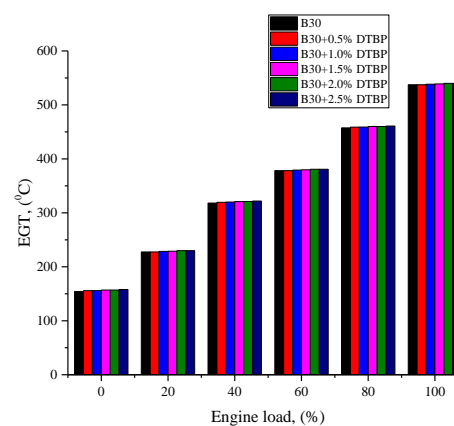


Fig. 60. Variation in exhaust gas temperature (°C) of engine with different engine loads using B30 with different

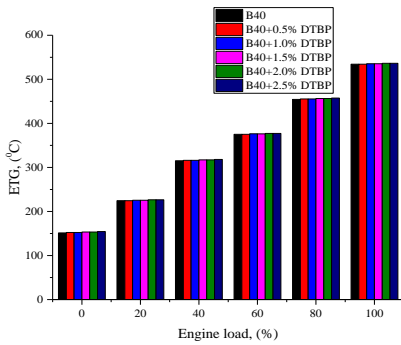


Fig. 61. Variation in exhaust gas temperature (°C) of engine with different engine loads using B40 with different proportion of DTBP

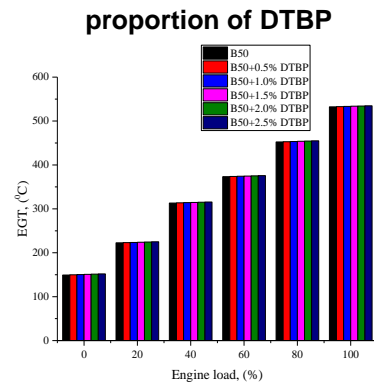


Fig. 62. Variation in exhaust gas temperature (°C) of engine with different engine loads using B50 with different proportion of DTBP

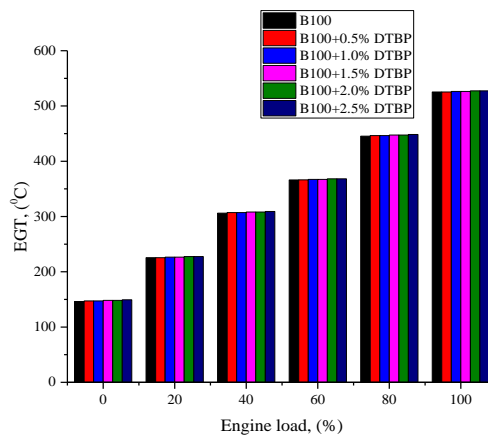


Fig. 63. Variation in exhaust gas temperature (°C) of engine with different engine loads using B100 with different proportion of DTBP

f) Sound level

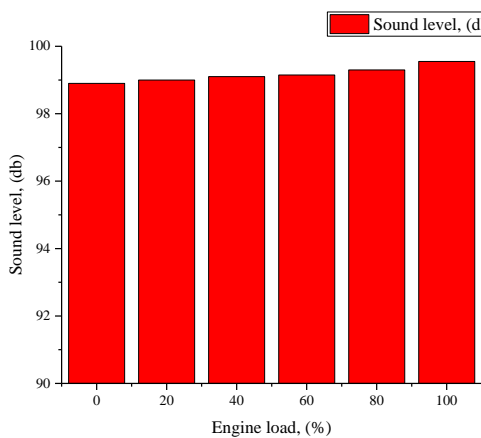


Fig. 64. Variation in sound level (db) of engine with different engine loads using 100 % diesel

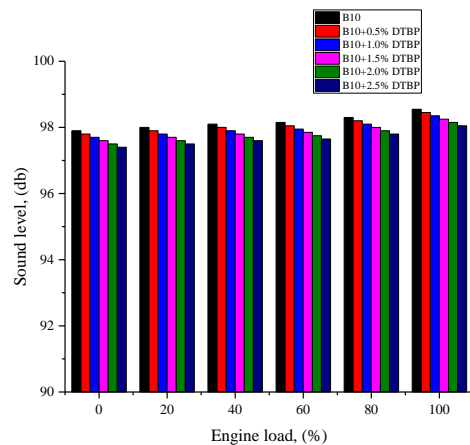
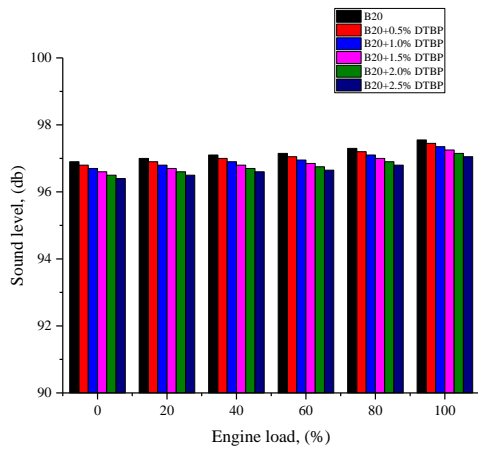
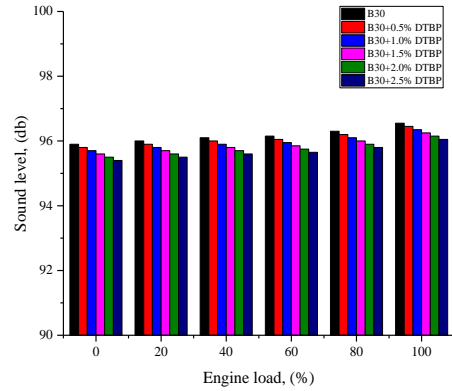


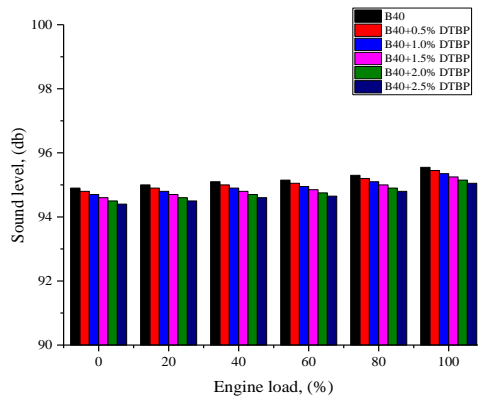
Fig. 65. Variation in sound level (db) of engine with different engine loads using B10 with different proportion of DTBP



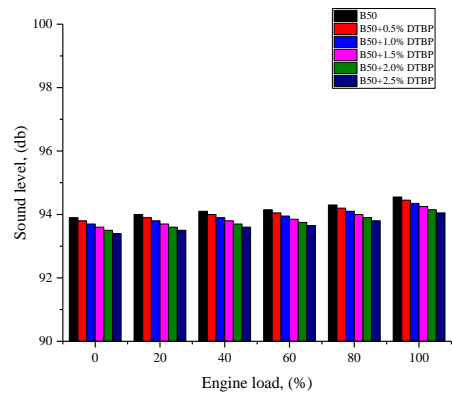
**Fig. 66. Variation in sound level (db) of engine with different engine loads using B20 with different proportion of DTBP**



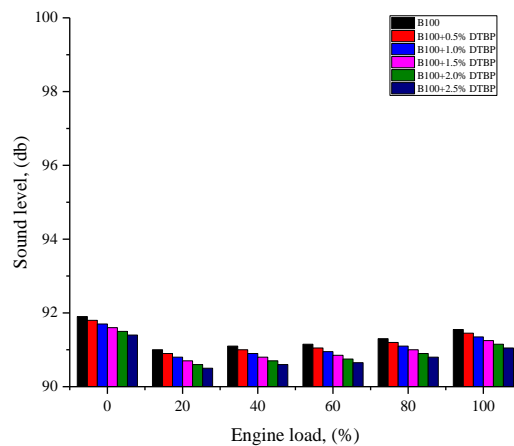
**Fig. 67. Variation in Sound level (db) of engine with different engine loads using B30 with different proportion of DTBP**



**Fig. 68. Variation in sound level (db) of engine with different engine loads using B40 with different proportion of DTBP**



**Fig. 69. Variation in sound level (db) of engine with different engine loads using B50 with different proportion of DTBP**



**Fig. 70. Variation in sound level (db) of engine with different engine loads using B100 with different proportion of DTBP**

Sound level (db) of CI engine was measured with different combination of blends with diesel and different load conditions. It was also showed that all the independent parameters significantly affect the Sound level (db) of the CI engine.

The variation in sound level (db) at diesel fuel (100%), blends of biodiesel with diesel (10, 20, 30, 40, 50 and 100%) with different proportion of DTBP (0.5, 1.0, 1.5, 2.0 and 2.5%) at various load conditions (0, 20, 40, 60, 80 and 100 %) is shown in Fig. 64 to Fig. 70. The maximum and minimum in sound level (db) was observed 90.49 (db) with B<sub>6</sub>A<sub>6</sub>L<sub>2</sub> and 98.55 (db) with B<sub>1</sub>A<sub>1</sub>L<sub>6</sub> treatment combination respectively.

As percentage of biodiesel increased as fuel in blend, sound level (db) was found to be increasing as compare diesel fuel. As per engine load was increased, sound level (db) was found to be increasing continuously. Engine load was increased, the combustion rate also increased and less time was available for the combustion and heat to dissipate to the surrounding leading to rise in sound level (db).

#### 4. CONCLUSIONS

The maximum and minimum break specific fuel consumption was found as 0.84 kg/kWh and 0.37 kg/kWh with B<sub>5</sub>A<sub>1</sub>L<sub>1</sub> and B<sub>3</sub>A<sub>5</sub>L<sub>5</sub> treatment combination, respectively. The maximum and minimum break specific energy consumption was found as 42.15 MJ/kWh and 17.51 MJ/kWh with B<sub>4</sub>A<sub>6</sub>L<sub>2</sub> and B<sub>1</sub>A<sub>1</sub>L<sub>6</sub> treatment combination, respectively. The maximum and minimum break power was found as 3.97 kW and 0.85 kW with B<sub>6</sub>A<sub>5</sub>L<sub>6</sub> and B<sub>4</sub>A<sub>1</sub>L<sub>2</sub> treatment combination, respectively. The maximum and minimum brake thermal efficiency was found as 30.55 % and 10.97 % with B<sub>1</sub>A<sub>6</sub>L<sub>6</sub> and B<sub>6</sub>A<sub>1</sub>L<sub>2</sub> treatment combination, respectively. The maximum and minimum carbon dioxide (CO<sub>2</sub>) was found as 9.82 % and 2.2 % with B<sub>6</sub>A<sub>6</sub>L<sub>6</sub> and B<sub>5</sub>A<sub>6</sub>L<sub>3</sub> treatment combination, respectively. The maximum and minimum carbon dioxide (CO<sub>2</sub>) was found as 0.107 % and 0.046 % with B<sub>1</sub>A<sub>1</sub>L<sub>6</sub> and B<sub>6</sub>A<sub>6</sub>L<sub>1</sub> treatment combination, respectively. The maximum and minimum nitrogen oxides (NO<sub>x</sub>) was found as 1325 ppm and 177 ppm with B<sub>6</sub>A<sub>6</sub>L<sub>6</sub> and B<sub>1</sub>A<sub>3</sub>L<sub>1</sub> treatment combination, respectively. The maximum and minimum hydrocarbons (HC) was found as 33.69 ppm and 7.21 ppm with B<sub>2</sub>A<sub>6</sub>L<sub>6</sub> and B<sub>6</sub>A<sub>3</sub>L<sub>1</sub> treatment combination, respectively. The maximum and minimum exhaust gas temperature was found as 546.53 °C and 146.32 °C with B<sub>1</sub>A<sub>6</sub>L<sub>6</sub> and B<sub>6</sub>A<sub>6</sub>L<sub>6</sub>

treatment combination, respectively. The maximum and minimum sound level was found as 90.49 (db.) and 98.55 (db.) with B<sub>6</sub>A<sub>6</sub>L<sub>2</sub> and B<sub>1</sub>A<sub>1</sub>L<sub>6</sub> treatment combination, respectively. Percentage of fuel cost saving per hour using biodiesel blends in CI Engine at full load condition with all the blends of biodiesel and diesel were 1.78, 3.61, 5.47, 7.38, 9.34 and 20.44 percentage, respectively. Percentage of fuel cost saving per hour using 50 % biodiesel + 50 % diesel + 1.5 % DTBP blends in CI Engine at full load condition was 0.23 % at best treatments (B<sub>5</sub>A<sub>3</sub>L<sub>6</sub>).

In all types of fuel, with increased percentage of load, the brake specific energy consumption (BSEC) of the engine decreased and brake thermal efficiency, fuel consumption rate and sound level (Db) were increased respectively. The increasing in brake thermal efficiency at higher loads was due to reduction in heat losses. The brake specific fuel consumption (BSFC) is significantly higher for B100 than pure diesel. This is due to higher viscosity and low calorific value as compared with diesel. The CO emission of the biodiesel was found more than that of diesel. This may be because of the higher viscosity and lower volatility of the fuels, which lead to formation of fuel rich zones resulting in inefficient combustion thus forming CO. Diesel, on the other hand, has good fuel spray properties and lower viscosity, which enable it to mix efficiently with air, burn evenly and hence emit lesser CO. The HC emissions of the B10, B20, B30, B40 and B50 fuel decreases with increases blend. This may be due to the presence of rich fuel air mixture at higher loads. On the other hand, the NO<sub>x</sub> emission was increased with increased biodiesel blend in diesel. The CO emission of the B10, B20, B30, B40 and B50 fuel was found to be more than that of diesel. This may be because of the higher viscosity and lower volatility of the fuels, which lead to formation of fuel rich zones resulting in inefficient combustion thus forming CO. Diesel, on the other hand, has good fuel spray properties and lower viscosity, which enable it to mix efficiently with air, burn evenly and hence emit lesser CO.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

#### REFERENCES

1. Mahesh PV, Deshpande A, Madras G. Synthesis of bio-diesel in supercritical

- alcohols and supercritical carbon dioxide. *Fuel*. 2010;89(2):1641-6.
2. Behçet R. Performance and emission study of waste anchovy fish biodiesel in a diesel engine. *Fuel Process Technol*. 2011;92(6):1187-94.
  3. Rao KS, Rajesh M, Venkateswarlu K. Analysis of exhaust emissions on diesel-biodiesel blends with ethyl hexyl nitrate additive and exhaust gas recirculation. *Int J Eng Sci Invent*. 2012;2(10):39-47.
  4. Velmurugan K, Gowtham S. Effect of cetane improver additives on emissions. *Int J Mod Eng Res*. 2012a;2(5):3372-5.
  5. Venkateswarlu K, Murthy BSR, Subbarao VV. The effect of exhaust gas recirculation and di-tertiary butyl peroxide on diesel-biodiesel blends for performance and emission studies. *Int J Adv Sci Technol*. 2013;54:49-60.
  6. Patel NK, Singh RN. Optimization of NO<sub>x</sub> emission from soya biodiesel fuelled diesel engine using cetane improver (DTBP). *Jordan J Mech Ind Eng*. 2014;8(4):213-7.
  7. Vadivela N, Somasundaram P, Krishnamoorthia M. Performance and emission characteristics of CI engine fueled with diesel-biodiesel (mahua/mustard) blend with diethyl ether additive. *J Chem Pharm Sci*. 2015;7:109-15.
  8. Raj CS, Karthikayan M. Effect of additive on the performance, emission and combustion characteristics of a diesel engine run by diesel-papaya methyl ester blends. *Int J Chem Sci*. 2016;14(4):2823-34.
  9. Dharmadhikari HM, Kumar PR, Rao SS. Performance and emissions of CI engine using blends of biodiesel and diesel at different injection pressures. *Int J Appl Res Mech Eng*. 2012;2(2):1-6.
  10. ASTM. Annual book of ASTM Standards. Philadelphia: American Society for Testing and Materials; 1983. p. 19103.
  11. Multani PS, Singh P. Performance and emission analysis of compression ignition engine using various emission reducing techniques. *Int Res J Eng Technol*. 2016;3(5):2120-7.
  12. Yilmaz N. Effects of intake air preheat and fuel blend ratio on a diesel engine operating on biodiesel-methanol blends. *Fuel*. 2012;94:444-7.
  13. Nevase SS, Gadge SR, Dubey AK, Kadu BD. Economics of biodiesel production from *Jatropha* oil. *J Agric Technol*. 2012;8(2):657-62.
  14. Özener O, Yüksek L, Ergenç AT, Özkan M. Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics. *Fuel*. 2014; 115:875-83.
  15. Pal A, Verma A, Kachhwaha SS, Maji S. Biodiesel production through hydrodynamic cavitation and performance testing. *Renew Energy*. 2010;35(3):619-24.
  16. Pathak BS. Use of bio-diesel in agricultural engines. In: Proceedings of the of National conference on bio-diesel for IC engine – technology and strategies for rural application, march, 2005. Bhopal, India: CIAE. 2004;62-86.
  17. Paul PJ, Dasappa S, Sridhar G, Sridhar HV. Biomass derived energy carriers as fuels in engines and Fuel cells. National Seminar on Biomass based Decentralized Power Generation, Org. by SPRERI. Vol. V(V). Nagar, January 21-22, 2005; 2005.
  18. Ramalingam S, Rajendran S, Ganesan P, Govindasamy M. Effect of operating parameters and antioxidant additives with biodiesels to improve the performance and reducing the emissions in a compression ignition engine – A review. *Renew Sustain Energy Rev*. 2018;81:775-88.
  19. Sahay J. Elements of agricultural engineering. Delhi: Standard Publishers Distributors; 2010.
  20. Salvi BL, Jindal S. A comparative study of engine performance and exhaust emissions characteristics of linseed oil biodiesel blends with diesel fuel in a direct injection diesel engine. *J Inst Eng (India) S C*. 2013;94(1):1-5.
  21. Sankaralingam RK, Venugopal T. Current trends on combustion control methods using fuel reactivities. *Int J Automot Mech Eng*. 2016;13(3):3788-811.
  22. Sekhar SC, Karuppasamy K, Sathiyamoorthy K. The Impact of various Nano Additives Blended with Diesel and biodiesel on DI Diesel Engine Performance, Combustion and Emission Parameters-A Mini-Review. *Asian J Res Soc Sci Humanit*. 2017;7(2):483-96.
  23. Sivashankar P, Weerahewa J, Pushpakumara G, Galagedara L. Economic analysis of *Jatropha* bio-diesel production in Sri Lanka. *Int J Multidiscip Stud*. 2016;3(1).
  24. Taymaz I, Sengil M. Performance and emission characteristics of a diesel engine

- using esters of palm olein/soybean oil blends. *Int J Veh Des.* 2010;54(2): 177-89.
25. Tsolakis A, Megaritis A. Exhaust gas assisted reforming of rapeseed methyl ester for reduced exhaust emissions of CI engines. *Biomass Bioenergy.* 2004;27(5): 493-505.
26. Velmurugan K, Gowthamn S. Effect of cetane improver additives on emissions. *Int J Mod Eng Res.* 2012b;2(5):3372-5.
27. Zhang ZH, Balasubramanian R. Investigation of particulate emission characteristics of a diesel engine fueled with higher alcohols/biodiesel blends. *Appl Energy.* 2016;163:71-80.

---

© 2024 Kachot et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*  
*The peer review history for this paper can be accessed here:*  
<https://www.sdiarticle5.com/review-history/111646>