Evaluation of Microalgae Biodiesel Blend Along with DTBP as an Ignition Enhancer on Diesel Engine Attributes

A. Gurusamy, V. Gnanamoorthi, P. Purushothaman, P. Mebin Samuel, and A. A. Muhammad Irfan

Abstract Biodiesel in an overall view has high oxygen content due to which it attains an attractive position to be a high-quality alternate fuel for a direct injection diesel engine. The combustion process along with the particulate matter will find a betterment when it is blended. In this work, commercially used pure diesel fuel (PD) is blended with 20% of an algae-based biodiesel, and also, di-tertiary-butyl peroxide is added in three different proportions (1, 3 and 5%). The performance and emission outcomes of all these blends under examination are studied using a diesel engine. All six parameters related to emission and performance are studied. From the results, it was seen that with the addition of DTBP in B20 blend increases the thermal efficiency and also the emission parameter values were found to be reduced, which provides a promising insight on the usage of DTBP additive in a diesel engine.

Keywords DTBP · Biodiesel · Microalgae · Performance · Emission

1 Introduction

The dwindling of the petroleum products day by day due to the increased demands and also the emission norms provide a greater threat for its successful usage. To

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fight this demand increase, bioenergy is implemented as a potential alternative. As a general fact, biodiesel has increased level of fatty acid content which is also indicated by many researchers (since vegetable oil or animal fats are used to produce biodiesel). It has higher oxygen, also renewable and biodegradable; due to this, the emission and greenhouse gases are reduced.

As a third-generation biofuel, algae biofuel has received significant interest and also importance, as this can be grown in any liquid ranging from wastewater to freshwater. This is mainly due to the improved yield rate and also the photosynthesis. The yield rate is higher since 70% of lipid is available in algae [1, 2]. The potential of microalgae in biodiesel production study done by Chen [3] between algae and other fuel shows that carbon supply, water supply and harvesting are the main parameters to be considered for calculating the overall cost of production of oil. In addition to the minimal land cost needed for algae, mixing and infrastructure cost are higher though it is shadowed by the higher yield of algae [4]. Photosynthesis process using sunlight is one of the major needs for the algae growth. Thus, being a renewable energy, algae fuel gets immense attention to meet the world-level energy demand. Algae oil can be considered as a major tool for reducing emissions. In addition to all the benefits, algae biomass after the extraction of oil does not pollute the environment [5].

2 Materials with Methods

2.1 Biodiesel Production

The purification of algae was done through a serial dilution process followed by plating for all the samples collected from many varieties (various water conditions). The dry microalgae (Botryococcus braunii) biomass is produced by filtration and drying after sample collection. Microalgae oil is separated from algal biomass by using solvent-expeller extraction method. Oil extraction was done using two solvents, namely hexane and ethers. Due to the introduction of these solvents, the algae membrane wall was ruptured and the oil was released. This oil is then placed inside an incubator and maintained at 80 °C to remove the excess of hexane solvents. In this process, 400 ml of oil was initially obtained, and finally, after the separation of hexane, only 380 ml of oil was left behind. This 380 ml of oil is the pure algae oil.

So as to remove the excess fatty acids, transesterification process is carried out using methanol and NaOH as catalyst. At a reaction temperature of about 70 °C, the mixture was constantly mixed at a speed of 800 rpm using a magnetic stirrer for a period of 1 h. Then, the mixture is allowed to cool to room temperature, and after a period of 8 h, algae methyl ester is separated from glycerin formed due to transesterification process using an apparatus called separatory funnel. Further, the algae methyl ester was processed for washing using hot water at a ratio of 1:5. This washing is repeated for three times to ensure the removal of dirt or any unwanted particles. Finally, the crude algae methyl ester was subjected to drying process. Here,

Table 1 Properties of test fuels

S. No	Properties	Diesel	B20	Measurement standards
1	Density @15 °C kg/m^3	876	816	ASTM D1298
2	Kinematic viscosity @40 °C in CST	2.9	3.120	ASTM D445
3	Calorific value (MJ/Kg)	44.43	40.42	ASTM D240
4	Cetane Index	48	47	ASTM D976
5	Flash point °C	60–80	60.49	ASTM D92
6	Sulfur content (%)	0.05	0.38	ASTM D5453
7	Ash content (%)	0.010	0.020	ASTM D482

the oil was subjected to an elevated temperature of 378 K for one hour after being held in a separatory funnel for 30 min and filtered. This is done to ensure the removal of water molecules in the oil and obtain purified microalgae methyl ester (MAME). Table 1 shows the comparison of diesel fuel properties with that of the measured values of B20 algae methyl ester blend.

Piloto-Rodriguez et al. [6] reviewed the implementation of algae methyl ester blend with diesel ranging from 5% till 100% and put forward that the values of B20 blend are comparable with that of diesel fuel with CO_2 and NO_X being on the higher side. Milano et al. [7] processed microalgae fuel to a substitute of diesel fuel in terms of power generation. The current stage of microalgae cultivation, including methods, production cost, energy ration, harvesting processes, adds their way to increase the cost of microalgae oil. Al-lwayzy et al. [8] performed a test on a diesel engine using microalgae Chlorella protothecoides biodiesel and suggested that the oil can be used purely without the need of blending it with diesel fuel and also in its blended form. Satputaley et al. [9] examined the combustion, emission and performance of both microalgae and the methyesther of the same, and proposed that the methyl ester of microalgae has better performance than the oil variant.

2.2 Di-Tertiary-Butyl Peroxide

The rate of initiation to form free radical and limiting the aromatic content of petroleum diesel fuel can be obtained through hydrotreating or adding an ignition enhancer [10]. Additive DTBP similarly to 2-EHN was recognized as an ignition enhancer for spontaneous ignition of diesel [11]. Kumar et al. [12] had investigated the effect of DTBP on the ethanol–cotton seed methyl ester blends in DICI engine. They observed that by adding DTBP fuel consumption, NO_X, CO, and UBHC were reduced significantly, and peak pressure of combustion is increased. Vallinayagam et al. [13] equated the results between both isoamyl nitrate (IAN) and DTBP on pine oil-neat diesel fuel blended in the ratio of 1:2 in a single-cylinder CI engine and proposed that HC and CO reduce and NOx increases. But, while adding DTBP, NO_X

Table 2 Properties of di-tertiary-butyl peroxide

S. No	Properties	DTBP
1	Composition	$C_8H_{18}O_2$
2	Flash point (°C)	6
3	Density (@20 °C) kg/m^3	0.79
4	Autoignition temperature (°C)	165
5	Molecular weight (g/mol)	146

emission is retarded when compared with biodiesel blend and biodiesel with isoamyl nitrate (IAN). The properties of DTBP are given in Table 2.

2.3 Experimental Setup

A four-stroke, single-cylinder DI diesel engine was used for the experimental analysis, whose specification is given in Table 3, and Fig. 1 gives a schematic diagram. The emission measurement is done with the help of AVL 444 di-gas analyzer, in which NOx and HC are denoted using ppm and amount of CO was denoted in % values. Smoke meter denoting smoke value in the Hartridge Smoke Unit is used for the measurement of smoke values. The reading was taken for different values of engine load ranging from 20 to 100% with 20% increment in each step for all the blends under test. In order to avoid any uncertainty error, the experiments were repeated for five times, and the average values were considered for all the further calculations. Uncertainty analysis is also done to show the change in values for each parameter under study, which is shown in Table 4. Overall uncertainty is measured to be 2.2%.

Table 3 Specification of the engine

Details	Specification
Type	Four stroke, Kirloskar TV1 model, compression ignition, direct injection and water cooled
Rated power and speed	5.2 kW and 1500 rpm
Number of cylinder	Single cylinder
Compression ratio	17.5:1
Bore& stroke	87.5 and 110 mm
Method of loading	Eddy current dynamometer
Type of injection	Mechanical pump-nozzle injection
Injection timing	23° before TDC
Injection pressure	220 bar
Combustion chamber	Hemispherical open type

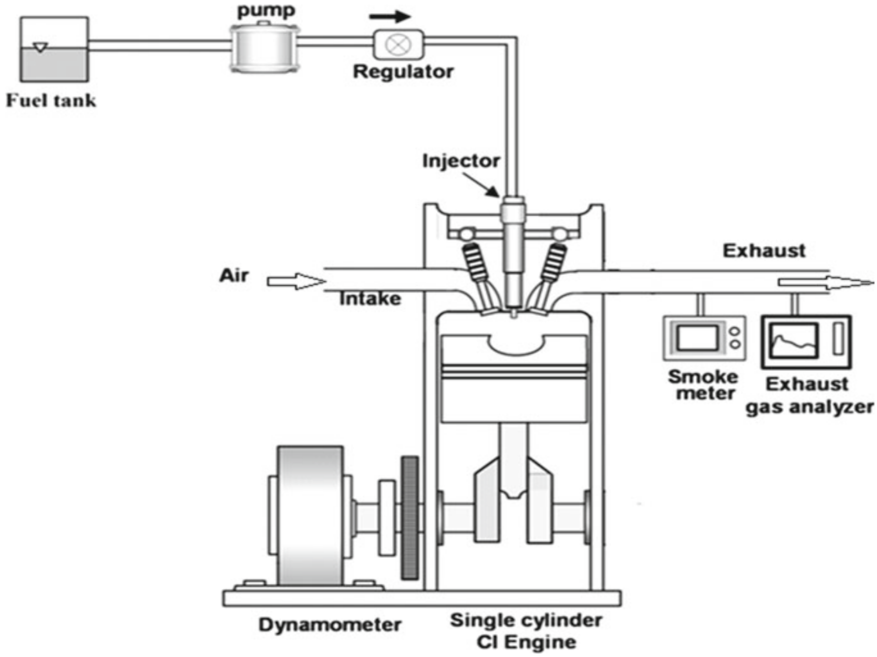

Fig. 1 Schematic diagram of the experimental setup

3 Results and Discussions

3.1 Brake Specific Energy Consumption

It is the amount of input energy needed to develop 1 KW power, and it is defined as the product of BSFC and calorific value of fuel. [14]. BSEC was examined, and the results show that 12.33, 13.12, 12.80, 12.65, 12.60 MJ/kWh for D100, B20 and B20 with 1, 3 and 5% DTBP at 100% load. Figure 2 shows the % differences in BSEC using B20 and B20 with 1, 3 and 5% DTBP compared to PD which is 6.4, 4, 2.9 and 1% at 100% load. The difference arose due to the physical and chemical properties of the fuel like heating and mass flow values. Other parameters such as density, viscosity and fuel injection method are also the main factors affecting the BSEC value of fuel [15, 16]. By increasing the percentage of DTBP in B20 blend, BSEC value is decreased, because of that increase in cetane value of mixture, which results from the engine consuming less fuel to one kilowatt power. BSEC value is equivalent to pure diesel for the blend of B20 with 5% blend [17].

Table 4 List of instruments and their accuracy and percentage uncertainties

Measurement	Type and manufacturer	Accuracy (%)	Uncertainty	Measurement technique
Load	Strain gauge, Sensotronics Sanmar	±10 N	±0.2	Load cell
Speed	Kubler, Germany	±10 rpm	±0.1	Magnetic pickup principle
Fuel flow measurement	Differential pressure Transmitter	±0.1 cc	±1	Volumetric measurement
CO	AVL exhaust gas analyzer, Austria	±0.02%	±0.2	NDIR technique
HC	AVL exhaust gas analyzer, Austria	±0.03%	±0.1	NDIR technique
NO_X	AVL exhaust gas analyzer, Austria	±12 ppm	±0.2	NDIR technique
Smoke	AVL smoke meter	±1 HSU	±1	Opacimeter
EGT indicator	Make Wika	±1 °C	±0.15	Thermocouple
Pressure Pick up	PCB, piezotronics	±0.1 kg	±0.1	Magnetic pickup principle
Crank angle encoder	Kubler, Germany	±1 deg	±0.2	Magnetic pickup principle

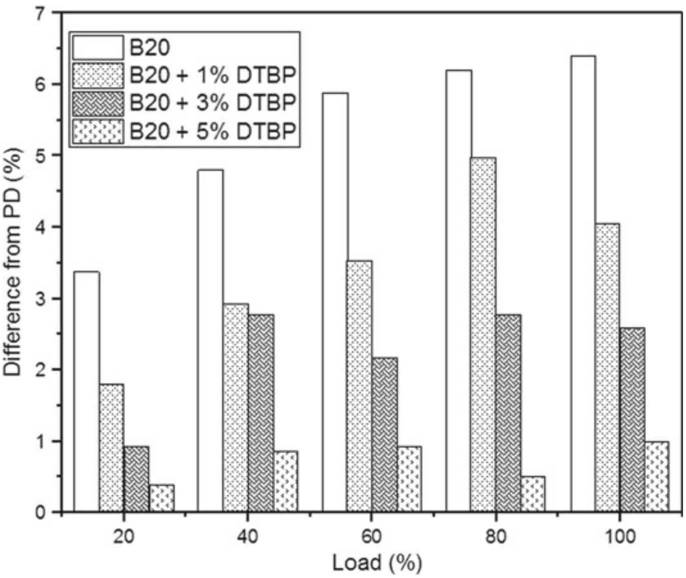

Fig. 2 Brake specific energy consumption percentage differences compared with PD

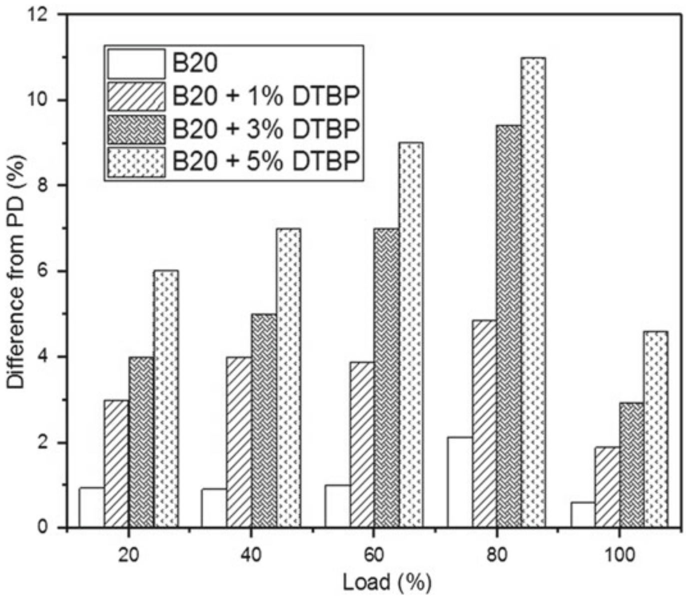

Fig. 3 Brake thermal efficiency percentage differences compared with PD

3.2 Brake Thermal Efficiency

It is the amount of work converted from the power from the fuel by the engine [18]. According to the Fig. 3, the percentage of differences in BTE using B20 and B20 with 1, 3 and 5% DTBP compared to PD are 0.6, 1.9, 2.9 and 4.6% at full load and BTE was found to be 29.54, 29.72, 30.1, 30.4 and 30.9% for D100, B20 and B20 with 1, 3 and 5% DTBP at full load condition. BTE is improved for B20 due to the proper use of heat energy, and also, the oxygen content existing in the microalgae methyl ester helps in improving the combustion process due to their improved evaporation factor [19]. The use of ignition enhancer (DTBP) substantially increases brake thermal efficiency, resulted in the reduction of IG delay period and advances in CT of B20 with 1, 3 and 5% [20]. By increasing the percentage of DTPB, brake thermal efficiency value is increased notably.

3.3 Carbon Monoxide Emission

Due to oxygen deficiency and lesser time period of CO to CO_2 conversion during combustion, CO emission is formed in IC engine. Figure 4 illustrates the percentage of differences in CO using B20 and B20 with 1, 3 and 5% DTBP compared to PD, which is −14, −28, −39 and −46% at full load and CO emission for D100, B20

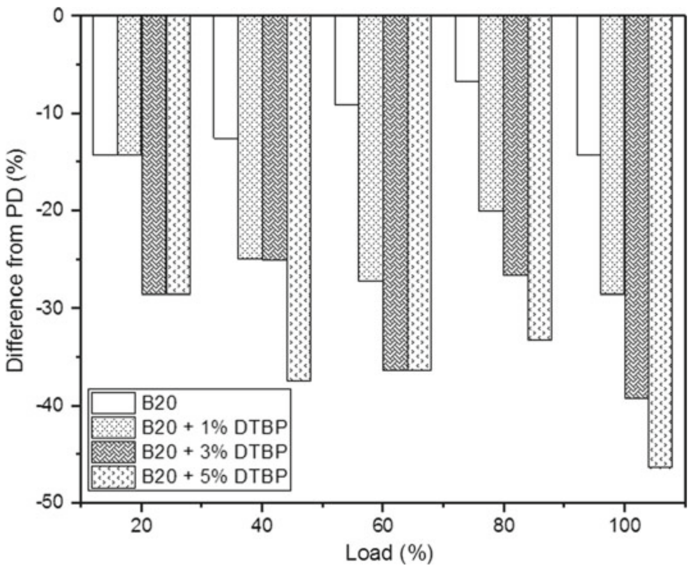

Fig. 4 Carbon monoxide emission percentage differences compared with PD

and B20 with 1, 3 and 5% DTBP fuel blends is 0.28%, 0.24%, 0.2%, 0.17% and 0.15% by volume at full load respectively. A negative sign indicates the reduction in percentage. CO emission is decreased to compare with B20. When compared to that of diesel, CO emission was reduced considerably. Since higher oxygen content present in the blends of biodiesel [21]. The involvement of DTBP improves the combustion process by increasing the combustion even in fuel rich zones; thereby, reduction in emission is achieved [22].

3.4 Unburned Hydrocarbon Emission

UBHC is a result of too lean or too rich fuel–air mixture inside the combustion chamber which could not get combusted or sustain the combustion, thereby oxidizing partially [23]. UBHC emission was found to be 53, 51, 47, 45 and 40 ppm for D100, B20 and B20 with 1, 3 and 5% DTBP fuel blends at 100% load. Figure 5 shows the percentage of differences in UBHC using B20 and B20 with 1, 3 and 5% DTBP compared to PD which is −3, −11, −15 and −25% at full load. Figure 5 acknowledges that HC emission is directly proportional with load for diesel and microalgae methyl ester(MAME); this is due to equivalence ratio improvement [24]. Emission of HC is greatly reduced considering B20 and B20 with 1, 3 and 5% DTBP. This study explains that HC reduction is attained with the help of oxygenated fuel. For B20 with 1, 3 and 5% DTBP, higher viscosity of B20 blend is neutralized with the reduced viscosity of DTBP additive [25].

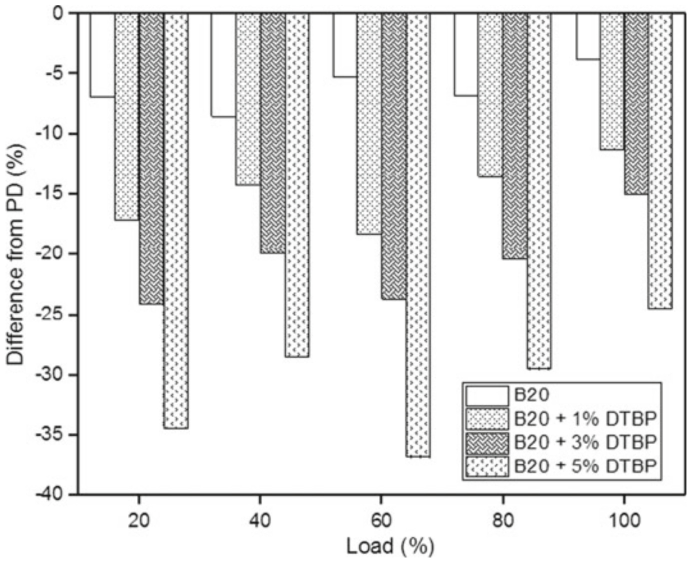

Fig. 5 Unburned hydrocarbon emission percentage differences compared with PD

3.5 Oxides of Nitrogen Emission

NOx is a combination of both NO and NO_2, which depends upon various parameters such as temperature, reaction time and surplus air [26]. NO_X emission for D100, B20 and B20 with 1, 3 and 5% DTBP fuel blends is found to be 925, 1045, 1022, 998 and 912 ppm at 100% load. Figure 6 demonstrates the percentage of differences in NO_X using B20 and B20 with 1, 3 and 5% DTBP compared to PD which is 13, 10, 8 and −1.5% at full load. NO_X is increased to compare with diesel with B20 at all load condition, due to increased O_2 concentration [27]. With the addition of 1, 3 and 5% of DTBP in B20, NO_X emission is decreased gradually, due to advances in combustion timing for B20 blend.

3.6 Smoke Emission

Smoke emission was found to be 53HSU, 42HSU, 39HSU, 35HSU and 24HSU for D100, B20 and B20 with 1, 3 and 5% DTBP fuel blends at 100% load. Figure 7 indicates the percentage of differences in smoke using B20 and B20 with 1, 3 and 5% DTBP compared to PD which is −20, −26, −34 and −45% at full load. Smoke emission is reduced for B20 and B20 with the addition of 1, 3 and 5% DTBP to compare with diesel. This is further supported by the presence of oxygen in fuel [27, 28].

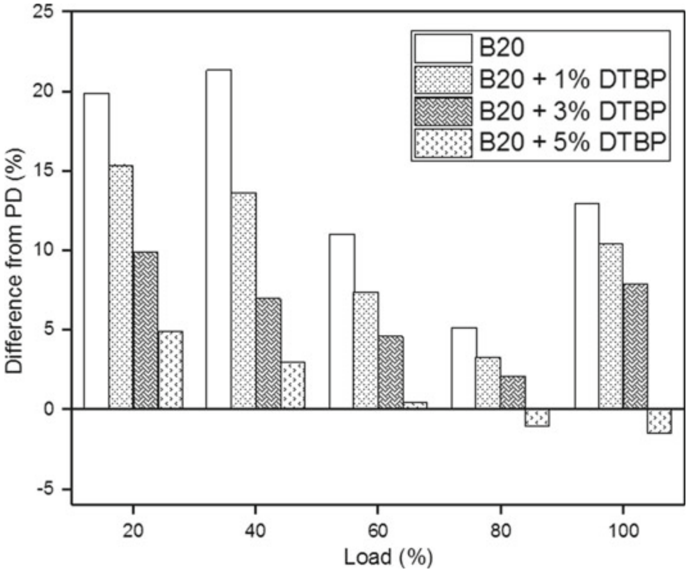

Fig. 6 Oxides of nitrogen emission percentage differences compared with PD

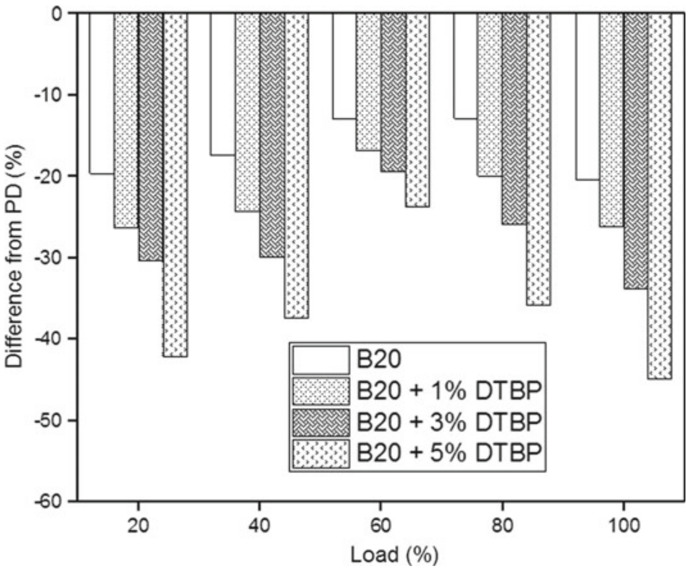

Fig. 7 Smoke emission percentage differences compared with PD

4 Conclusion

The effect of DTBP addition with microalgae methyl ester (MAME) biodiesel blend (B20) in a diesel engine and thereby the effects of DTBP addition (1, 3 and 5%) in MAME (B20) on engine's working behavior characters (performance, emissions) were examined. The results from the study are further given below:

1. BSEC of B20 with 5% DTBP is equivalent to pure diesel (PD) and produced maximum brake thermal efficiency.
2. The emission tests exposed that smoke, UBHC, CO and NOx emissions improved for B20 fuel blend with the addition of DTBP.
3. The DTBP additive can produce satisfactory results when blended with a biodiesel–diesel blend.
4. B20 blends of MAME was able to run properly and also produced satisfactory results when blended with DTBP without any major changes in the engine.

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