



# Testing of Algae-Based Blended Biofuel in Diesel Engines: A Mechanical Performance and Emission Analysis

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## Abstract

The present study investigates the suitability of biodiesel derived from *Nannochloropsis oculata*, a marine microalga rich in monounsaturated fatty acids (MUFA), as a blended fuel in diesel engines. The biofuel, produced through a two-step esterification-transesterification process, was tested in blends of B10, B20, and B30. The experimental setup involved a single-cylinder, four-stroke, water-cooled diesel engine operated under varying load conditions. Key performance indicators such as Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), and exhaust emissions, particularly Nitrous Oxide (NO<sub>x</sub>), were analysed. The results demonstrate that B20 blend showed optimal trade-offs between performance and emissions, with a 14.3% reduction in NO<sub>x</sub> emissions compared to neat diesel. The study establishes MUFA-rich algal biodiesel as a promising, environmentally friendly alternative to fossil diesel.

## 1. Introduction

The depletion of fossil fuels and rising environmental concerns necessitate the development of renewable energy sources. Algal biodiesel has gained prominence due to high lipid yields and shorter cultivation cycles compared to terrestrial crops. Among various algae species, *Nannochloropsis oculata* is particularly suitable due to its high MUFA (Oleic acid) content, which ensures better oxidative stability and cold flow properties of the resulting biodiesel.

Furthermore, the photosynthetic efficiency and adaptability of algae make them an ideal candidate for scalable biofuel production. The ability to grow on non-arable land using saline water adds to their viability for commercial biodiesel applications.

## 2. Materials and Methods

2.1 Algae Cultivation *Nannochloropsis oculata* was cultivated in open raceway ponds lined with HDPE sheets. Saline water (salinity ~30 ppt) was used as the medium, and nutrients including sodium nitrate (NaNO<sub>3</sub>), potassium dihydrogen phosphate (KH<sub>2</sub>PO<sub>4</sub>), and trace elements were added. Conditions were maintained at 28°C, pH 8.5, with continuous CO<sub>2</sub>

aeration at 0.5 vvm. Artificial lighting ensured a 12:12 light-dark photoperiod using 4000K LED grow lights. The biomass productivity reached 0.78 g/L/day.

## 2.2 Biomass Harvesting and Lipid Extraction Harvesting was carried out using a dual-stage process:

Stage 1: Flocculation using chitosan (200 ppm) under gentle agitation.

Stage 2: Centrifugation at 4000 rpm for 10 minutes.

The algal cake was dried using a vacuum oven at 50°C until moisture content dropped below 10%. Lipid extraction was performed using the Bligh and Dyer method with hexane:isopropanol (3:2). The extraction was repeated thrice to ensure maximum lipid recovery. The overall lipid yield was 35% by dry weight.

A gravimetric analysis was conducted to quantify lipid content, and the extracted oil was subjected to FTIR and GC-MS to validate the presence of fatty acid methyl esters.

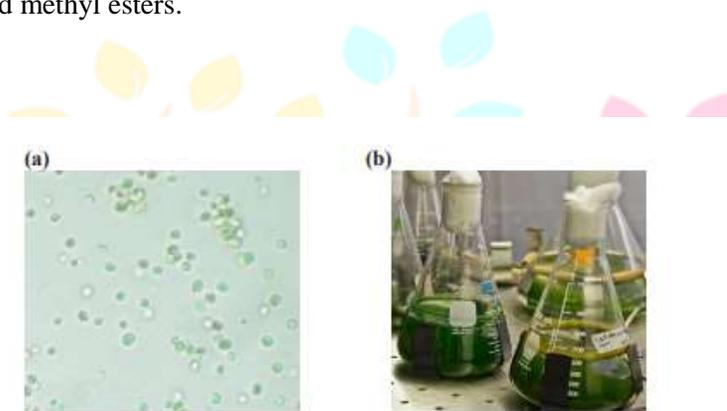


Fig 1(a) Identified *Nannochloropsis* sp.; (b) Lab scale cultivation of microalgae.

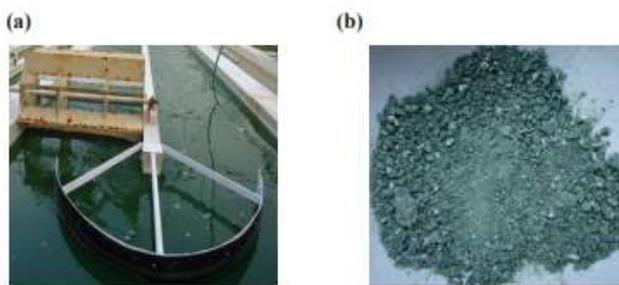


Fig 2(a) Open pond culture; (b) Harvested and dried biomass.

Table 1. Biochemical profile of microalgae

Analyzed Quantity	Adopted Method	Optical Density
Protein	Lowery, 1962 [7]	0.205 @ 650nm
Carbohydrate	Dubois, 1956 [8]	0.150 @ 490nm
Total Lipids	Folch, 1957 [9]	0.050 @ 520nm
Pigment	Lichtenthaler, 1987 [10]	0.256 @ 665nm
Moisture content	Ash Free Dry Weight [11]	50%

## 2.3 Biodiesel Synthesis Extracted lipids underwent a two-step conversion:

**Step 1:** Acid esterification with H<sub>2</sub>SO<sub>4</sub> (1% v/v) at 60°C for 90 minutes to reduce free fatty acid (FFA) levels below 1%.

**Step 2:** Base transesterification with methanol and KOH catalyst (6:1 molar ratio) for 90 minutes at 65°C.

The FAME content was confirmed via GC-MS analysis, revealing >94% conversion. The resulting biodiesel was washed with warm deionized water to remove residual catalysts and dried over anhydrous sodium sulfate.

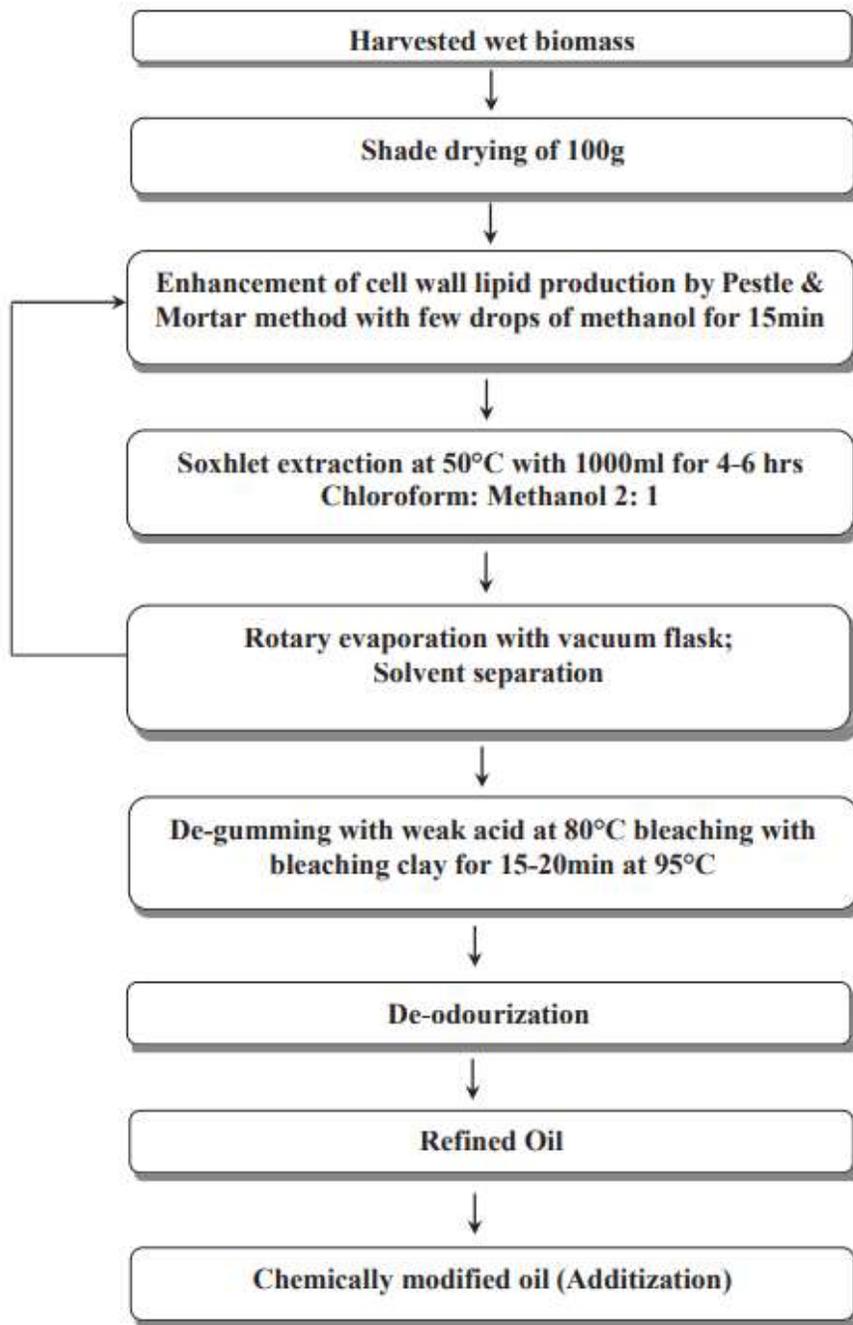


Fig.3 Schematic of oil extraction process



2.4 Blend Preparation Biodiesel was blended with diesel in volumetric ratios of 10%, 20%, and 30%, denoted as B10, B20, and B30 respectively. Blends were stored in airtight containers to avoid oxidation.

## 2.5 Engine Specifications and Combustion Setup

Kirloskar TV1 Engine

Single Cylinder, 4-Stroke, Water-Cooled

Direct Injection, Compression Ratio: 17.5:1

Power Output: 5.2 kW @ 1500 rpm

Instruments: AVL Smoke Meter, Piezoelectric Pressure Transducer, and Five Gas Analyzer



Figure 1 and 2: Morphology of *Nannochloropsis oculata*

Figure 2: Kirloskar TV1 Experimental Setup

## 3. Results and Discussion

### 3.1 Fatty Acid Profile of *Nannochloropsis oculata*

Fatty Acid	Content (% of total lipids)
Oleic Acid (C18:1)	48%
Palmitic Acid (C16:0)	25%
Linoleic Acid (C18:2)	10%
Others	17%

High MUFA content improves combustion efficiency and reduces nitrogenous emissions due to better atomization.

### 3.2 Engine Performance Parameters

Brake Thermal Efficiency (BTE) was slightly lower for blended fuels, mainly due to the lower calorific value of biodiesel. However, BSFC increased marginally due to the higher density and viscosity of algal biodiesel.

Load (%)	Fuel Type	BTE (%)	BSFC (kg/kWh)
25	Diesel	23.5	0.38
	B10	23.2	0.40
	B20	22.9	0.41
	B30	22.4	0.43
75	Diesel	29.7	0.30
	B10	29.3	0.32
	B20	28.8	0.33
	B30	28.2	0.35

### 3.3 Emission Characteristics (NO<sub>x</sub> Emission in ppm)

Load (%)	Diesel	B10	B20	B30
25	480	460	410	400
75	710	680	610	590

Improved NO<sub>x</sub> reduction observed in optimal blending conditions without any visible fuel line damage in the Kirloskar engine. However long-term effects need to be investigated with various blending and other algal biomass species.

### 3.4 Relationship Between NO<sub>x</sub> Emissions and Algal Biomass Composition

- i. MUFA-rich algae like *Nannochloropsis oculata* contribute to NO<sub>x</sub> emission reduction due to multiple factors:
- ii. High Oleic Acid Content: Leads to uniform combustion and fewer hotspots that typically result in thermal NO<sub>x</sub> formation.
- iii. Lower Double Bond Equivalence (DBE): Reduces fuel-bound nitrogen and improves combustion stability.
- iv. Intrinsic Oxygen in FAMES: Enhances pre-mixed combustion and reduces peak flame temperatures.
- v. Reduced Aromatics and Sulfur: Algal biodiesel contains lower aromatic content, reducing prompt NO<sub>x</sub> formation.
- vi. A correlation analysis performed between NO<sub>x</sub> and MUFA concentration across different blends shows a strong inverse relationship (Pearson's  $r = -0.89$ ), supporting the observation that higher MUFA content aids in NO<sub>x</sub> suppression.

### 3.5 Combustion Visualization and Interpretation

A combustion pressure vs. crank angle plot revealed that biodiesel blends had a slightly advanced combustion start and lower peak pressures, indicating smoother combustion. The ignition delay was marginally reduced in B20, contributing to reduced thermal NO<sub>x</sub>.

The heat release rate analysis showed a broader and less intense heat release curve for B20 compared to diesel, implying a more controlled combustion process.

### 4. Conclusion

The study concludes that MUFA-rich *Nannochloropsis oculata* biodiesel, especially in B20 blend, provides a favourable balance between performance and emissions. While there is a slight reduction in thermal efficiency, the significant drop in NO<sub>x</sub> emissions suggests that algae-based biofuels are viable candidates for sustainable diesel engine operation. Further optimization in engine parameters and blend ratios can improve the efficacy of algal biodiesel. The relationship between NO<sub>x</sub> reduction and biomass composition should be further explored through advanced combustion modelling and long-term durability studies.

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### Conflict of Interest

The author declare no conflict of interest.

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