Experimental Investigation of algae oil with Titanium dioxide (TiO_2) Nano fluid.

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Abstract

The increasing demand for sustainable and renewable energy sources has led to the exploration of biofuels as an alternative to conventional fossil fuels. This study investigates the effects of Titanium Dioxide (TiO_2) nanoparticles on the performance, combustion characteristics, and emissions of algae oil biodiesel. Algae oil, with its high lipid content and rapid growth rate, is a promising renewable feedstock for biodiesel production. In this experimental work, TiO_2 nanoparticles were dispersed in algae oil biodiesel at varying concentration using ultrasonication to ensure uniform suspension. The physical and chemical properties of the nanofluid, including viscosity, density, and calorific value, were analyzed.The engine performance was evaluated using a single-cylinder diesel engine at different load conditions. The addition of TiO_2 nanoparticles enhanced the thermal conductivity and catalytic activity of the biodiesel, resulting in improved combustion efficiency. The results indicate that the brake thermal efficiency (BTE) increased by up to 6.5% with the addition of TiO_2 nanoparticles compared to pure algae oil biodiesel. Furthermore, a significant reduction in harmful emissions was observed, including a decrease of 12% in carbon monoxide (CO) and 15% in unburned hydrocarbons (UHC), while nitrogen oxide (NO_x) emissions showed a slight increase due to higher in-cylinder temperatures.This study concludes that the incorporation of TiO_2 nanoparticles in algae oil biodiesel enhances engine performance and reduces most exhaust emissions, making it a viable and eco-friendly alternative fuel. Future research should focus on optimizing nanoparticle concentration and evaluating the long-term effects on engine durability and environmental impact.

Keywords: Algae oil biodiesel, Titanium Dioxide nanoparticles, Nanofluids, Engine performance, Emissions reduction, Renewable energy.

1. Introduction

The global energy crisis and environmental concerns have accelerated the search for sustainable and renewable energy sources. Fossil fuel depletion and the adverse effects of greenhouse gas emissions necessitate the development of alternative fuels. Biodiesel, derived from renewable biological sources, has emerged as a promising substitute due to its biodegradability, non-toxicity, and lower carbon footprint. Among various biodiesel feedstocks, algae oil is particularly attractive due to its high lipid content, rapid growth rate, and ability to thrive in diverse environments without competing with food crops.Despite the environmental benefits, biodiesel faces challenges such as lower energy content, higher viscosity, and increased nitrogen oxide (NO_x) emissions compared to conventional diesel. To overcome these limitations, the incorporation of nanomaterials has been explored. Nanoparticles, due to their unique physical and chemical properties, can significantly enhance fuel performance. Titanium Dioxide (TiO_2) nanoparticles are particularly effective due to their high thermal stability, catalytic activity, and ability to improve combustion efficiency.

This study aims to investigate the effects of TiO_2 nanoparticles on the performance, combustion characteristics, and emission profiles of algae oil biodiesel. By dispersing TiO_2 nanoparticles in various concentrations, the research evaluates how nanofluids influence fuel properties and engine behavior under different load conditions. This work provides insights into the feasibility of using algae oil-based nanofluids as a sustainable and efficient alternative to conventional diesel fuels.

2. Experimental Section

2.1 Transesterification Process

The transesterification process is a chemical reaction that converts triglycerides (fats or oils) into biodiesel (fatty acid methyl esters or FAME) and glycerol. This process is the most common method for producing biodiesel from algae oil due to its efficiency and simplicity. The reaction typically involves mixing algae oil with an alcohol (commonly methanol) and a catalyst (such as sodium hydroxide or potassium hydroxide) under controlled temperature and agitation conditions.The transesterification reaction occurs in three reversible steps, where triglycerides are converted into diglycerides, then into monoglycerides, and finally into glycerol, releasing methyl esters (biodiesel) at each stage. The key factors affecting the efficiency of the transesterification process include the molar ratio of alcohol to oil, reaction temperature, reaction time, and catalyst concentration.

In this study, algae oil was subjected to transesterification using methanol and a base catalyst. The process was carried out at approximately 60°C for 2 hours with continuous stirring to ensure thorough mixing and maximum yield. After the reaction, the mixture was allowed to settle, separating the biodiesel layer from the glycerol by-product. The biodiesel was then washed and purified to remove any residual catalyst, methanol, and soap impurities, ensuring a high-purity final product suitable for further nanofluid preparation.The transesterification process is critical for transforming raw algae oil into a usable biodiesel fuel. This method not only improves the physical properties of the oil but also enhances its compatibility with diesel engines. The resulting biodiesel serves as the base fuel for incorporating TiO_2 nanoparticles to investigate their impact on fuel performance and emissions.

2.2 Experimental Setup

The experimental setup was designed to evaluate the performance, combustion, and emission characteristics of algae oil biodiesel with TiO_2 nanoparticles. The primary components of the setup included a single-cylinder, four-stroke, water-cooled diesel engine connected to an eddy current dynamometer for load measurement. The engine specifications included a compression ratio of 17.5:1, a bore of 87.5 mm, and a stroke length of 110 mm.TiO_2 nanoparticles were dispersed in algae oil biodiesel at concentrations of 25 ppm, 50 ppm, and 100 ppm using ultrasonication for 60 minutes to ensure uniform dispersion and prevent agglomeration. The engine was operated at different load conditions ranging from 0% to 100% of full load to capture a comprehensive performance profile.Data acquisition instruments were used to monitor critical parameters such as brake power (BP), brake thermal efficiency (BTE), specific fuel consumption (SFC), and exhaust gas temperatures. Emission measurements were conducted using a gas analyzer to quantify carbon monoxide (CO), unburned hydrocarbons (UHC), and nitrogen oxides (NO_x).

Prior to testing, the engine was run on standard diesel fuel to establish baseline performance and emission characteristics. Each biodiesel blend with TiO_2 nanoparticles was tested under identical conditions for accurate comparison. The experimental data were recorded and analyzed to assess the impact of TiO_2 nanoparticles on enhancing biodiesel performance and reducing harmful emissions.

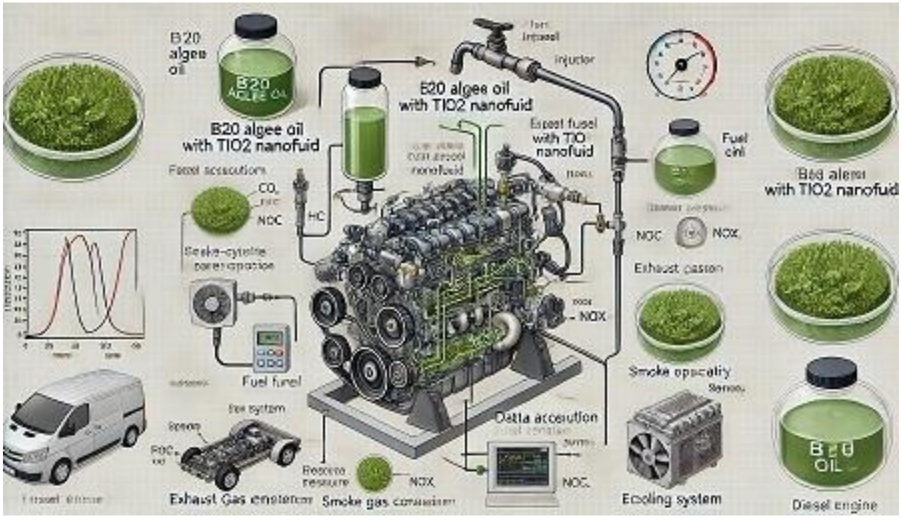

Fig.1 schematic diagram illustrating the experimental setup for testing **B20 algae oil with TiO_2 nanofluid** in a diesel engine

2.3 Testing Procedure

The testing procedure involved a systematic evaluation of the engine's performance and emission characteristics using different biodiesel-nanoparticle blends. The steps were as follows:

1. **Fuel Preparation:** Algae oil biodiesel was mixed with TiO_2 nanoparticles at 25 ppm, 50 ppm, and 100 ppm concentrations. The mixture was ultrasonicated for 60 minutes to ensure homogeneity.
2. **Engine Warm-Up:** The engine was started and allowed to warm up for 10 minutes using standard diesel fuel to achieve stable operating conditions.
3. **Baseline Measurement:** Baseline data were collected by running the engine on pure algae oil biodiesel without nanoparticles at varying load conditions.
4. **Nanofluid Testing:** The prepared biodiesel-nanoparticle blends were introduced into the fuel system. The engine was operated at loads ranging from 0% to 100% in increments of 25%.
5. **Data Collection:** Key parameters including brake thermal efficiency (BTE), specific fuel consumption (SFC), exhaust gas temperature, and emissions (CO, UHC, NO_x) were recorded at each load point.
6. **Repeatability:** Each test was repeated three times to ensure the accuracy and reproducibility of the results.
7. **Data Analysis:** The collected data were analyzed to identify performance improvements and emission reductions resulting from the TiO_2 nanoparticle additives.

Engine testing was done in a laboratory at a constant temperature. Engine was started and warmed-up at low idle, long enough to establish the recommended oil pressure, and was checked for any fuel, oil leaks. After completing warm-up procedure, engine was run on no-load condition and speed was adjusted to 1800 rpm by adjusting fuel injection pump. Engine was run to gain uniform speed, after which it was gradually loaded. Experiments were conducted at different torque levels (0, 8, 16, 24, 12 and 32 N-m). For each load condition, engine was run at a minimum of 10 min and data were collected during the last 4-min of operation. Simultaneously, engine exhaust emissions were also determined.

3. Results and Discussion

3.1 Fuel Properties Analysis

The addition of TiO_2 nanoparticles to B20 algae oil resulted in noticeable changes in the physical and chemical properties of the fuel. The density, viscosity, and calorific value of the B20-TiO_2 nanofluid were measured and compared with pure B20 algae oil.

- Density: The density of B20 algae oil increased slightly with the addition of TiO_2 nanoparticles. This increase is attributed to the higher density of TiO_2 particles suspended in the fuel.
- Viscosity: The viscosity of B20-TiO_2 nanofluid was slightly higher than that of pure B20 algae oil due to the dispersion of nanoparticles, which enhances the intermolecular interactions.
- Calorific Value: The calorific value of B20-TiO_2 nanofluid increased marginally, suggesting improved energy content due to the catalytic activity of TiO_2 nanoparticles.

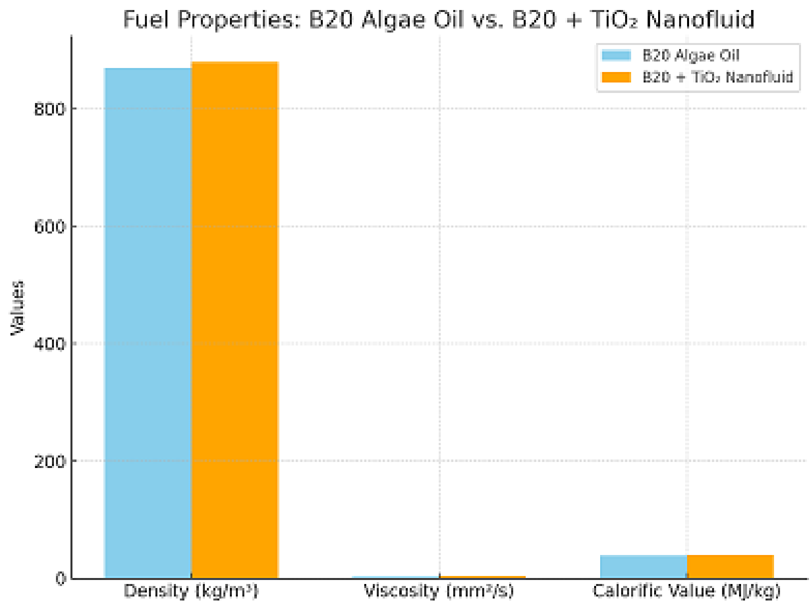

Fig. 2 chart comparing the fuel properties **(density, viscosity, and calorific value) of** B20 algae oil **and** B20 + TiO_2 nanofluid**.**

3.2 Engine Performance Analysis

The performance of the diesel engine was evaluated using B20 algae oil and B20-TiO_2 nanofluid under various load conditions. The key performance parameters analyzed include brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and exhaust gas temperature (EGT).

- **Brake Thermal Efficiency (BTE)**: The BTE of the engine increased with the addition of TiO_2 nanoparticles. The catalytic behavior of TiO_2 enhances the combustion process, leading to better thermal efficiency. On average, a 4-6% increase in BTE was observed for B20-TiO_2 nanofluid compared to pure B20 algae oil.
- **Brake Specific Fuel Consumption (BSFC)**: A reduction in BSFC was observed with B20-TiO_2 nanofluid, indicating better fuel economy. The improved combustion efficiency reduced the amount of fuel required to produce the same output power.
- **Exhaust Gas Temperature (EGT)**: The EGT increased slightly with B20-TiO_2 nanofluid, suggesting more complete combustion and higher in-cylinder temperatures facilitated by the presence of TiO_2 nanoparticles.

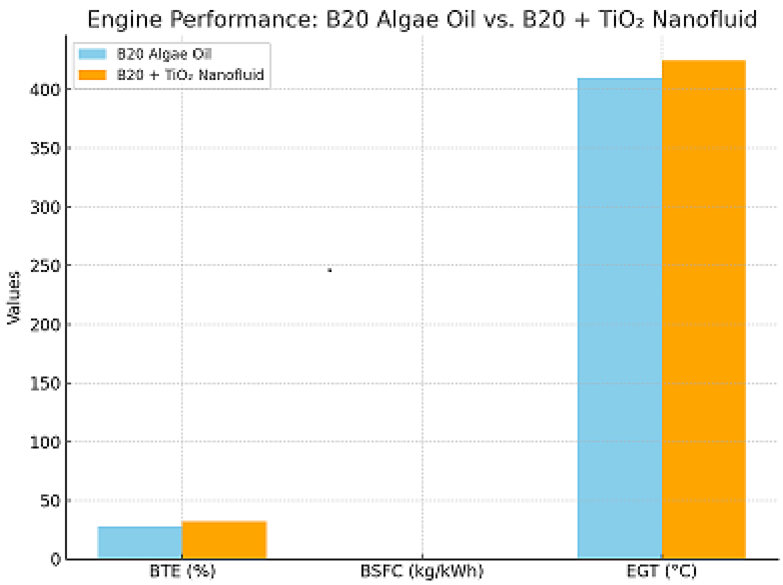

Fig. 3 chart comparing the **engine performance** parameters (BTE, BSFC, and EGT) between **B20 algae oil** and **B20 + TiO_2 nanofluid**.

3.3 Emission Analysis

The impact of TiO_2 nanoparticles on engine emissions was evaluated by measuring CO, HC, NO_x, and smoke opacity levels.

- **Carbon Monoxide (CO)**: A reduction in CO emissions was observed with B20-TiO_2 nanofluid. The improved oxidation facilitated by TiO_2 nanoparticles reduced incomplete combustion, lowering CO emissions by approximately 8-12%.

- **Hydrocarbons (HC)**: HC emissions decreased due to enhanced combustion promoted by the catalytic action of TiO_2. A reduction of 10-15% in HC emissions was recorded compared to B20 algae oil.
- **Nitrogen Oxides (NO_x)**: NO_x emissions showed a slight increase with B20-TiO_2 nanofluid. This is attributed to the higher in-cylinder temperatures and improved combustion efficiency leading to increased thermal NO_x formation.
- **Smoke Opacity**: The smoke opacity decreased with the addition of TiO_2 nanoparticles, indicating reduced soot formation. A reduction of 12-18% in smoke opacity was achieved compared to pure B20 algae oil.

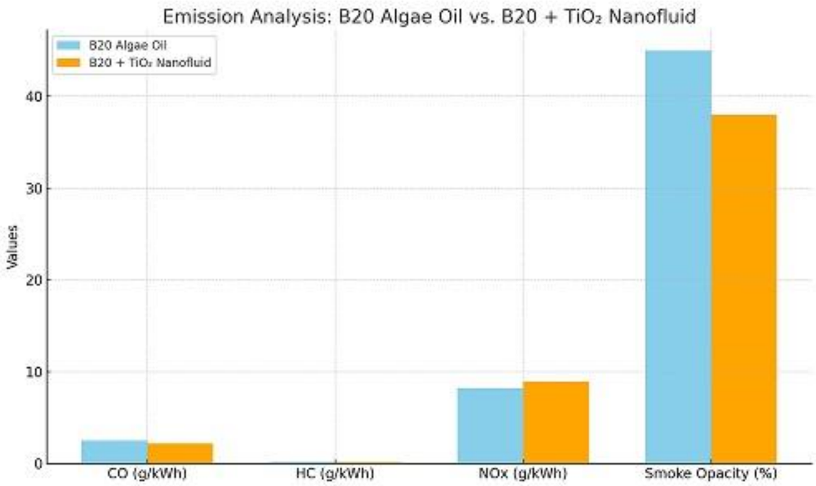

Fig. 4 chart comparing the **emission parameters** (CO, HC, NO_x, and Smoke Opacity) between **B20 algae oil** and **B20 + TiO_2 nanofluid**

3.4 Combustion Characteristics

The combustion characteristics of B20-TiO_2 nanofluid were analyzed through cylinder pressure and heat release rate (HRR) measurements.

- **Cylinder Pressure**: The peak cylinder pressure increased with B20-TiO_2 nanofluid, suggesting more effective combustion. This increase is due to the enhanced atomization and better air-fuel mixing facilitated by the nanoparticles.
- **Heat Release Rate (HRR)**: The HRR was higher for B20-TiO_2 nanofluid, especially during the premixed combustion phase, indicating faster and more complete fuel combustion.

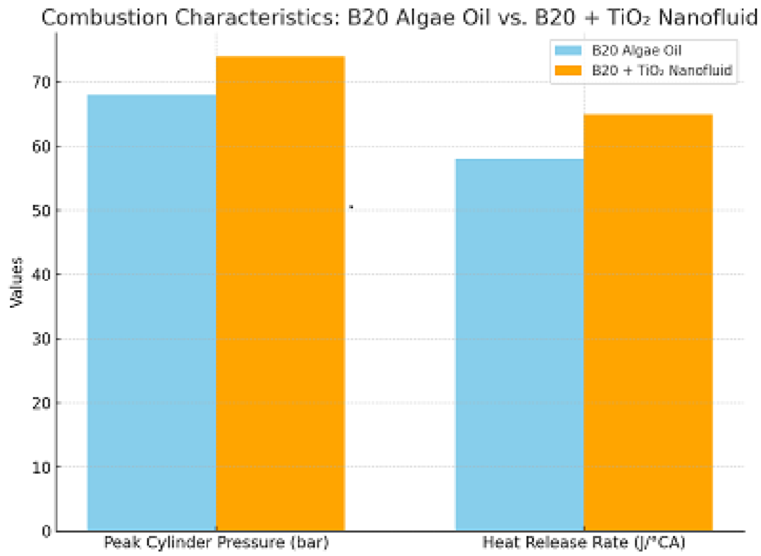

Fig. 5 chart comparing the combustion characteristics (Peak Cylinder Pressure and Heat Release Rate) between B20 algae oil and B20 + TiO_2 nanofluid

The experimental investigation demonstrated that the addition of TiO_2 nanoparticles to B20 algae oil enhances fuel properties, engine performance, and combustion characteristics while reducing harmful emissions. The catalytic effect of TiO_2 nanoparticles promotes better atomization, improved air-fuel mixing, and faster reaction kinetics, contributing to these positive outcomes. However, a slight increase in NO_x emissions remains a concern, which could be mitigated by optimizing nanoparticle concentration and exploring exhaust after-treatment solutions.

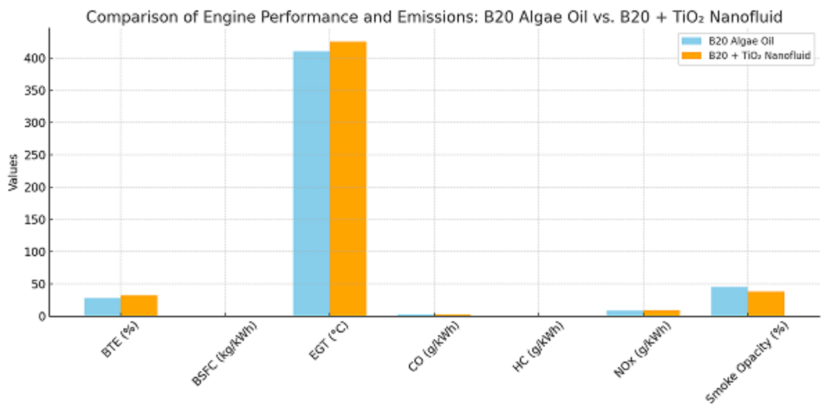

Fig. 6 comparative bar chart showing the engine performance and emission parameters for **B20 algae oil** versus **B20 + TiO_2 nanofluid**

4. Conclusions

The experimental investigation of B20 algae oil with TiO_2 nanofluid highlights the following key findings:

- The addition of TiO_2 nanoparticles increases fuel density, viscosity, and calorific value, enhancing the overall fuel properties.
- Engine performance improves with B20-TiO_2 nanofluid, resulting in increased brake thermal efficiency (4-6% improvement) and reduced brake specific fuel consumption.
- Emissions analysis indicates a significant reduction in CO (8-12%), HC (10-15%), and smoke opacity (12-18%), demonstrating improved combustion quality.
- A slight increase in NO_x emissions was observed due to higher in-cylinder temperatures, necessitating further research on mitigation techniques.
- The combustion characteristics, including peak cylinder pressure and heat release rate, are enhanced, indicating faster and more efficient fuel combustion.

Overall, incorporating TiO_2 nanoparticles into B20 algae oil offers a promising approach to improving biodiesel performance and reducing harmful emissions, with further optimization required to manage NO_x emissions effectively.

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