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Experimental Investigation of Performance and Emission of Microalgae Chlorella Vulgaris in Variable Compression Ratio Engine

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ABSTRACT:

This study aims to conduct an experimental examination concerning the performance and emission characteristics of the microalgae Chlorella vulgaris when utilized in an internal combustion engine featuring a variable compression ratio. This investigation seeks to explore the effects of employing Chlorella vulgaris in such an engine on both the performance parameters, such as power output and fuel consumption, as well as the emission characteristics, including the levels of nitrogen oxides, carbon monoxide and unburnt hydrocarbons in the exhaust gases. By performing this experimental investigation, it is to contribute to the existing body of knowledge in the field of alternative fuels and renewable energy sources, specifically in terms of the utilization of microalgae as a potential substitute for conventional fossil fuels in internal combustion engines.

KEYWORDS:

Renewable energy; Microalgae; Chlorella vulgaris; Performance; Emissions

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1. Introduction

Transportation energy demand is rising and internal combustion (IC) engines are the dominant source. However, fossil fuel depletion and rising prices have spurred the quest for alternative fuels. Although the efficiency in diesel engines is lower than diesel, biodiesel could replace diesel [1, 2]. To build a biodiesel-powered diesel engine with superior performance, progressive combustion and emissions, engine components and systems have been modified. Biodiesel, bioethanol and biomethanol are promising alternative fuels for IC engines. These biofuels, made from "biomass," or plant and animal waste, can cut greenhouse gas emissions. Biofuels can cut CO_2 emissions without major infrastructure improvements, making them a "carbon neutral" or "carbon negative" power source for cars, trucks and planes. Biofuels have been investigated as Jet-A fuel alternative in aviation. When mixed with Jet-A fuel at lower concentrations, microalgae biofuels reduce CO_2 emissions and increase performance. Boomadevi et al [3] reported low energy content, hence higher addition percentages yielded poor results. Ethanol, methanol, i-butanol-n-butanol and acetone have been studied as renewable biofuels for spark ignition (SI) engines. Ethanol improves engine performance and reduces pollutant emissions, but cold starting is difficult.

Despite being poisonous and incompatible with engine components and systems, methanol improves engine emissions and performance. Elfasakhany [4] predicted that dual-blended biofuels will dominate the future, with ethanol-methanol (EM) biofuel being the best. Kalra et al [5] examined IC engine performance utilising biodiesel mixes like Calophylum Inophylum oil. Lower biofuel blends increased brake thermal efficiency (BTE) and decreased brake fuel specific consumption (BSFC). Rehman et al [6] numerically studied CI engines by employing microalgae biodiesel blends, including Chlorella protothecoides. They found that microalgae biodiesel mixes affected in-cylinder pressure (CP), heat release rate (HRR), BTE, specific fuel consumption and pollutants. The impacts on compression ratio (CR) engines were not reported. Sangeetha et al [7] evaluated how adding CNTs and alumina to Chlorella vulgaris microalgae biofuel affected emissions. Adding alumina and carbon nanotubes to microalgae biofuel Chlorella vulgaris reduced greenhouse gas emissions and improved combustion and performance.

Karthikeyan et al [8] studied diesel engine emissions with prototype dual fuel mixtures containing Chlorella vulgaris oil and showed that diesel engines running on pilot fuel blends of Chlorella vulgaris oil and turpentine oil emit nitrogen oxides comparable to diesel while creating less smoke, unburnt hydrocarbons (UBHC) and carbon monoxide (CO). When spirulina algal methyl ester

(SAME) was added to conventional diesel, Dawody et al [9] investigated the performance and emissions of a variable CR diesel engine. They concluded that microalgae biodiesel blends can improve or worsen engine performance and emissions depending on the blend and engine circumstances. Adding SAME to ordinary diesel resulted in changes in BSFC, CO_2 emissions, BTE, exhaust gas temperature and UBHC, CO_2 and NO_X emissions. The vibration and acoustics of a direct injection engine using microalgae biodiesel blends are studied by Hanz et al [10]. Experiments showed microalgae mixes reduce the vibration and noise. Higher microalgae blends minimise noise and vibration more. Kalea et al [11] analysed how combining microalgae biodiesel with diesel and CR affects diesel engine performance and emissions. The results showed that greater CRs improve BTE and BSFC.

Debowski et al [12] compared the emissions from biodiesel and diesel engines. Microalgae biodiesel emitted less CO and NO_X than rapeseed biodiesel. By full analysis, biofuels have shown their potential as alternative fuels for IC engines and efforts are underway to improve their performance, emissions and efficiency. The research shows that microalgae biodiesel blends in IC engines can affect engine performance and pollution [13]. This experiment evaluates a variable CR engine fueled by Chlorella vulgaris' performance and emissions. Controlled testing will assess the engine's efficiency, power output, combustion behaviour and emissions profile utilising Chlorella vulgaris as a renewable and sustainable fuel. Comparing CRs to engine performance and emissions will show the feasibility and environmental benefits of employing microalgae-based biofuels in IC engines.

2. Materials and methods

The microalgae Chlorella vulgaris can be used as a sustainable biofuel since its high lipid content can be transesterified into biodiesel. Rapid expansion and versatility could help sustainable biofuel production. Chlorella vulgaris, which stores lipids, could be grown in regulated conditions for biofuel research. The algae were freeze-dried after reaching the requisite lipid content. The Folch technique mechanically removed the lipid content. The main liquid for lipid extraction is chloroform, methanol and water. If the solvent phase rich in lipids is extracted from the bio-mass residue, a crude lipid extract is obtained. Lipid extraction was accelerated with 0.75% NaCl and a 2:1 chloroform-methanol ratio. After that, we centrifuged the mixture at 5000 rpm for 30 minutes at room temperature. For biodiesel, lipids are mixed with alcohol and a catalyst to form fatty acid methyl esters. Methanol of 12:1 in KOH was transesterified at 60°C for 2 hours. Diesel and microalgae biodiesel can have its properties assessed according to ASTM standards.

Microalgae biodiesel has a lower calorific value than diesel (46.5 MJ/kg vs. 39 MJ/kg). Microalgae biodiesel has a Cetane number of 52, whereas conventional diesel has a Cetane number of 46. In order to assess the efficacy and quality of microalgae biodiesel, certain characteristics and metrics are crucial. The distinct chemical makeup of biodiesel causes it to have a viscosity and density that are higher than those of regular diesel fuel. Because it has a flash point higher than 64°C, this material can safely replace diesel fuel. The properties of diesel and biodiesel are shown in Table 1.

Table 1: Properties of diesel and biodiesel

Property	Diesel	Microalgae biodiesel	ASTM std.
Calorific Value(MJ/kg)	46.5	39	
Cetane number	46	52	47
Density (g/cm^3)	0.84	0.89	0.86-0.90
Viscosity, cSt	3.3	3.8	3.5-5.0
Flash point (ºC)	88	125	100 (min)
Pour point (ºC)	-8	-18	(-15 to -16)

3. Experimental details

An eddy current dynamometer and a single-cylinder diesel engine were used to measure the power and emissions of the engine in the investigation. In order to measure the emissions of HC, CO and NO_X in real-time, an exhaust gas analyzer was used. In order to gather performance data, the engine data acquisition and control system was used. For fuel consumption measurements, we used the SAJ fuel consumption metre and for emissions data, we used the AVL DI gas 444 gas analyzer. The velocity of air mass flow was measured using an U-tube millimetre. A single-cylinder compression ignition engine was used to test the efficiency of microalgae biodiesel and diesel blends. For the purpose of making diesel and biodiesel blends more stable, a surfactant was added at a dosage of 2%. The layout of experimental test engine is shown in Fig. 1. Five different fuels were used as test fuel for experimentation. Standard diesel (SD), BD20 (20% of microalgae biodiesel), BD40 (40% of microalgae biodiesel), BD60 (60% of microalgae biodiesel) and BD100 (100% of microalgae biodiesel).

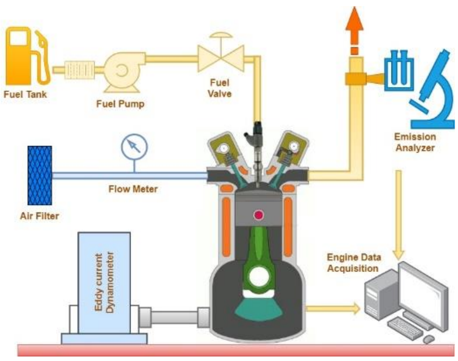

Fig. 1: Experimental layout of test engine

4. Results and discussion

Fig. 2 shows the BTE of diesel and microalgae biodiesel blends. There is a positive association between the load level and the BTE. The BTE of biodiesel blends B40, B60 and B100 are considerably lower than diesel's owing to the fuel-bound oxygen's lower heating value and higher density. The only exception to this is B20 blend, which exhibits a BTE that is comparable to diesel's owing to the abundant oxygen that improves the combustion efficiency. This is happening even for the denser B20 blends. Compared to diesel, BTE for B20 blend was

1.24% higher. However, when the blend was increased to a higher level, the BTE for B40, B60 and B100 was dropped by 4.22%, 8.61% and 11.10%, respectively. Fig. 3 shows the BSFC results for diesel and microalgae biodiesel blends. As the load rose from zero to full, BSFC has decreased. Loading raises the combustion temperature, reducing ignition latency and BSFC. Microalgae biodiesel and its blends exceed diesel due to their higher viscosity. BSFC for B20 was 6.23% lower than base diesel, but the BTE for B40, B60 and B100 was 9.96%, 20.42% and 26.99% higher.

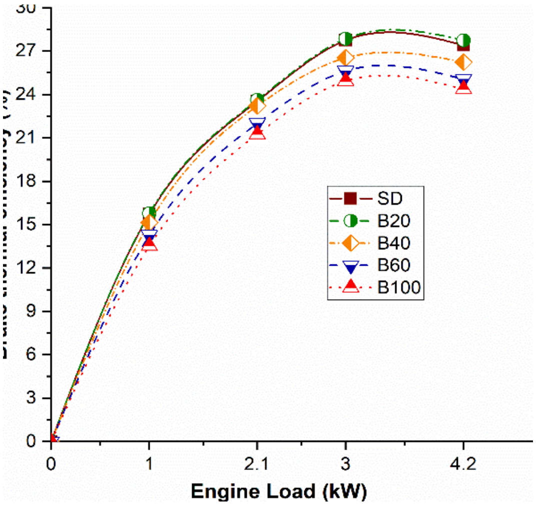

Fig. 2: BTE of biodiesel blends

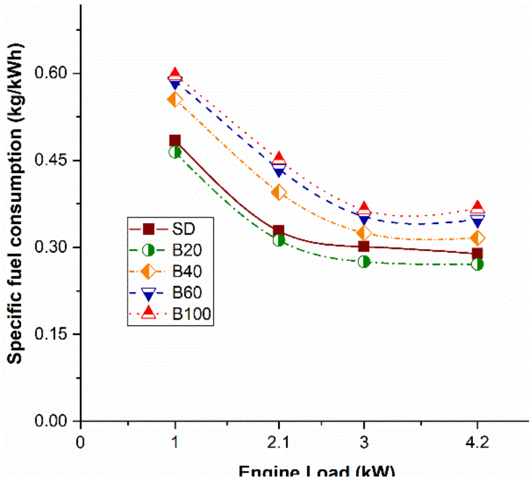

Fig. 3: BSFC of biodiesel blends

Diesel fuel and blends of microalgae biodiesel blends produce different amounts of UBHC emissions, as seen in Fig. 4. The formation of UBHC is more rapidly caused by diesel, which is composed of hydrogen and carbon. B20 blend exhibited lower levels of UBHC generation in comparison to diesel. UBHC emissions are higher at higher blending levels compared to B20 and diesel due to higher viscosity of biodiesel, which causes incomplete combustion and as a result, more UBHC. Higher UBHC emissions are seen under full load settings as compared to no load conditions. When the load is larger, more fuel is pumped into the cylinder, leading to higher emissions compared to lower loads. While B20's UBHC emissions were 8.7% lower than base diesel, B40, B60 and B100 had much higher blend UBHC emissions, measuring 21.43%, 45.65% and 58.5% higher, respectively. An obvious and statistically significant rise in CO content is noted when the load goes from zero to full as shown in Fig. 5. Lack of an adequate supply of air and fuel is the main and most important component that causes CO to be produced during combustion [14, 15]. The high oxygen concentration of biodiesel is a defining feature that significantly enhances the fuel's combustion rate compared to diesel particularly in B20 blends. Crucially, running the engine at higher loads causes the fuel consumption to outstrip the air supply, which in turn causes the CO emissions to skyrocket.

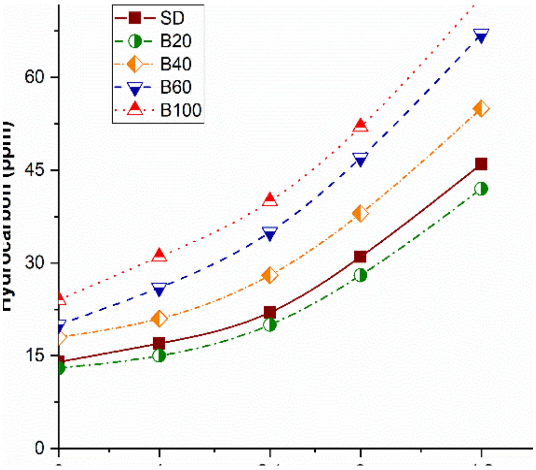

Fig. 4: UBHC emission of biodiesel blends

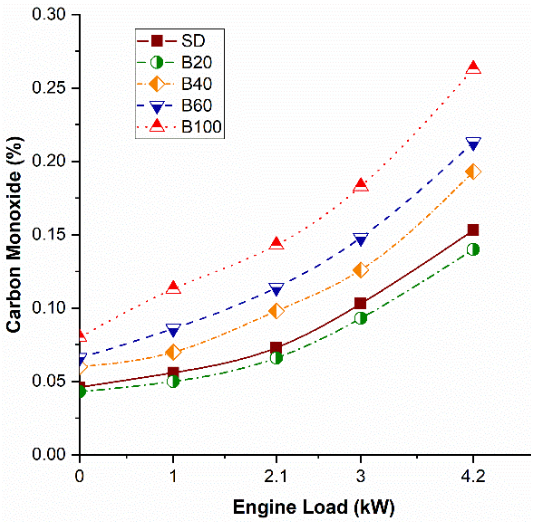

Fig. 5: CO emission of biodiesel blends

Fig. 6 shows the quantities of NO_X released when diesel and biodiesel mixtures are burned. Between the no-load and full-load operating conditions, NO_X emissions tend to rise. An obvious fact is that when the load increases, the combustion temperature also rises, leading to higher amounts of NO_X emissions. Because of its higher oxygen concentration, microalgae biodiesel is more likely to emit NO_X than diesel fuel. The NO_X emissions from B20 were 4.38% more than those from base diesel. By contrast, NO_X emissions were 13.29% greater for B40, 20.58% greater for B60 and 22.92% greater for B100 compared to other blends. The amount of smoke produced is significantly affected by the load on the engine. As the engine's work load increases, the smoke density also increases [16, 17]. Diesel and biodiesel blends both emit smoke, as shown in Fig. 7. The thickest smoke was produced by burning diesel fuel. When compared to diesel fuel, the amount of smoke emissions increases when biodiesel is added because biodiesel blends cause incomplete combustion. When switching from base diesel to B20, smoke emissions dropped by 7.89%. When compared to diesel, B40, B60 and B100 respectively produced 11.43%, 26.32%, and 44.74% more smoke.

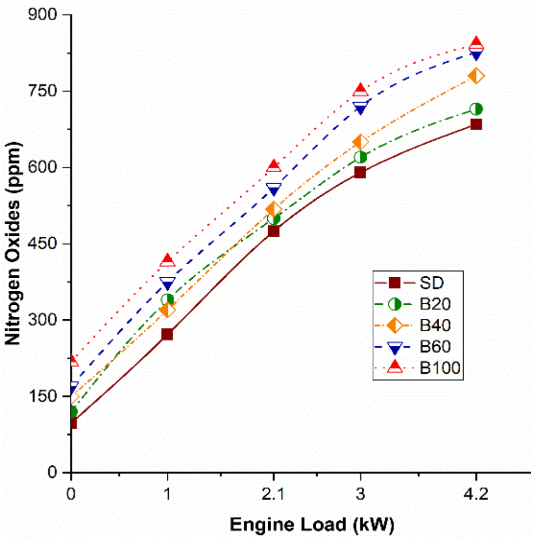

Fig. 6: NOx emission of biodiesel blends

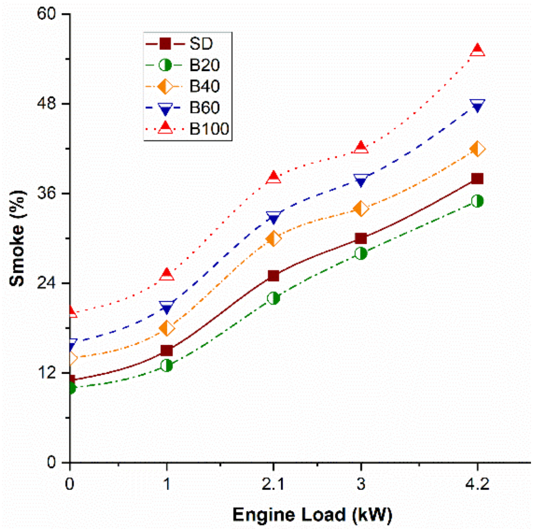

Fig. 7: Smoke emission of biodiesel blends

5. Conclusion

Chlorella vulgaris was tested in a variable CR IC engine for performance and emissions. BTE for B20 was marginally higher than the base diesel by 1.24%, but BTEs for B40, B60 and B100 blends were declined by 4.22%, 8.61% and 11.1%. B20 had 6.23% lower BSFC than base diesel, whereas B40, B60 and B100 blends yielded 9.96%, 20.42% and 26.99% greater BTE. B20 had less UBHC emissions than base diesel. CO emissions were 8.5% lower than base diesel for B20 but 28.57%, 39.22% and 71.9% higher for B40, B60 and B100 respectively. Base diesel emitted 4.38% less NOx than B20. B20 reduced smoke emissions by 7.89% when compared to that of base fuel.

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