Journal of Algal Biomass Utilization
J. Algal Biomass Utln. - Copyright © PHYCOSPECTRUM
ISSN: 2229 – 6905

Evaluation of algae Bio-fuel as the next generation alternative fuel and its effects on engine characteristics: A Review

Joshi, M. P[1,2] and S S Thipse[3]

[1] Symbiosis International (Deemed University), Gram: Lavale, Tal: Mulshi, Dist: Pune, Maharashtra, India. Pin: 412115,
[2] MIT Academy of Engineering, Dehu Phata, Alandi (D), Pune - 412 105, Maharashtra, India
[3] The Automotive Research Association of India, Survey No. 102, Vetal Hill, off Paud Road, Kothrud, Pune - 411 038. Pune - 411 004, India

Abstract

Algae biofuels represent one of the most promising solutions to the current global energy crisis and climate change because of their potentially high yield, high production rate, biodegradability, non toxicity, carbon neutrality, and low emission profile. Moreover, non-arable land and non-potable water can be used for production of algae biofuel with minimal attention and resource consumption. In this study, we compared algae biofuel and other conventional biofuels in terms of performance as well as combustion and emission characteristics of compression ignition engines. A thorough review of the available relevant literature and a critical analysis has been presented. The study results indicate that algae biofuel blends can be efficiently used as alternative, renewable, and ecofriendly fuels without major modification to the existing engine. Algae biofuels contain an optimal combination of unsaturated fatty acids and oxygenated nature, the presence of excess oxygen molecules facilitates complete combustion of fuel resulting in better thermal performance along with reduced undesirable emission. This clean and green fuel is definitely the fuel of the future.

Keywords: Algae biofuel, Performance, Combustion, Emission, green fuel

Introduction

Identifying feasible sources of renewable and eco-friendly energy that can meet long-term global energy needs is closely connected with world security, economic prosperity, and a high quality of life. Among the available renewable energy sources, the most crucial energy source in near future is biomass [1]. Algae biomass can be a promising energy source because algae are extremely competent biological producers of oil on Earth. Algae are considered to be one of the oldest living organisms and fastest growing plants on Earth. Algae comprise an enormous and diverse group of the fastest growing photosynthesizing microscopic aquatic organism ranging from unicellular to multicellular forms with simplistic structure. The diversity of algae, with more than 300,000 species, is considerably greater than that of plants. Depending on the species, algae produce large amounts of different types of lipids, carbohydrates, and complex oils in varying proportions over a short period [2-4].

This paper provides a comparison between algae-based biofuel with other conventional biofuels. Moreover the performance, combustion, and emission characteristics of algae biofuel blends and their suitability of use in compression ignition engines are discussed.

Comparison between algae oil and other conventional bio-diesels

Currently, non edible oils are considered potential feedstocks for biodiesel production because of the ‘food versus fuel’ crisis associated with the use of edible oils for biodiesel production [5]. Algae can be produced throughout the year at an exponential growth rate; they can double their biomass in just 3.5 hrs. They can produce up to 30 times more energy per hectare than the best oil seed crops. The actual advantage of algae over plants is their metabolic flexibility which offers opportunities for modifying their biochemical pathways and cellular compositions.

The large-scale production of oil-rich algae biomass for biofuel production is generally a complex and expensive process and is technologically more challenging than growing crops. Mostly algae oil consists of triacylglycerol with three fatty acid molecules attached to a glycerol backbone [6]. Thus, the fatty acid profile, growth rate, survivorship, and physiochemical properties of the algae biomass are crucial factors for selecting a suitable algae species for biofuel production [7]. Currently, continuous efforts are being directed towards obtaining optimal permutations of algae strains and their growth conditions. Open ponds are the oldest, simplest, and cheapest systems for large-scale cultivation, whereas photobioreactors offer a relatively safe closed culture environment. Although the use of these reactors yields higher productivity within less time than that of open ponds, the capital and operating cost of the reactors is higher than that of the open pond system. Both these approaches are hindered by substantial technical and economic hurdles. Thus, currently, a combination of both systems, called 'hybrid system' is the most logical choice for the cost-effective cultivation of high yielding strains of algae. Algae require sunlight, CO_2, water, and inorganic salts for photosynthesis. By manipulating these requirements, increasing the quantity of oil-rich biomass is possible. Lipid accumulation in algae increases considerably during conditions of environmental stress such as nutrient deficiency, and nitrogen shortage. The production of 100 tons of algae biomass fixes approximately 183 tons of CO_2. Thus, many researchers suggest that CO_2 released by power plants and nutrients from waste water treatment plants in the vicinity can be potentially used for commercial large-scale algae biomass production. Thus, algae are involved in several activities that can maintain the eco-logical balance and control pollution. Moreover, they can assist in mitigating global warming [8].

Table 1. Comparison between the fuel properties of algae oil and conventional biodiesel

Sr No	Properties	ASTM 6751-12	EN 14214	Diesel	Algae oil	Palm oil	Jatropha	Karanja
1	Calorific value (kJ/kg)	--	--	43000	40072	37800	39000	39200
2	Density (kg/L)	086-0.90	0.86-0.90	0.84	0.912	0.850	0.940	0.874
3	Viscosity @ 40^{0}C (mm^2/s)	1.9-6.0	3.5-5.0	2.64	5.06	4.32	4.8	5.21
4	Cetane number	>47	>51	53.3	46.5	55	50	50
5	Flash point (^{0}C)	100-170	>120	71	145	167	135	100
6	Acid value (mg KOH/g)	<0.5	<0.5	0.0	0.14	0.24	0.4	043
7	Oxidation stability @ 110^{0}C	3.0	>6.0	--	6.76	10.3	3.2	--
8	Oil yield (L/ha)	--	--	--	58000	5950	1892	2590

Algae are the most efficient sunlight-driven cell factories that convert CO_2 into useful biofuels and other high-value bio-actives. The physiochemical properties of a biofuel depend on its fatty ester profile and structural properties, such as carbon chain length, degree of unsaturation, and branching of the chain. These parameters of the fatty acid esters influence cetane number, heat of combustion, cold flow viscosity, and exhaust emissions. The carbon chain length is favourable in most algae biofuels, but the high degree of unsaturation hinders their use due to the adverse effect on cetane number, oxidative stability, and heat of combustion. Such unsaturation of algae oil can simply be reduced through partial catalytic hydrogenation of oil. The high flash point facilitates safe usage and storage, whereas the biodegradability of algae biofuel is particularly advantageous in environmentally sensitive areas. The calorific value of algae biofuel was approximately 10% less than that of diesel. The relatively higher density and viscosity of algae biofuel may result in poor fuel atomization characteristics with deep penetration into the cylinder [9]. The presence of excess oxygen molecules facilitates complete combustion of the fuel, resulting in reduced emission. Algae oil does not contain any sulphur hence, SOx emission is not a concern. Moreover, algae oil has lubricating properties that reduce the wear and tear of metallic components. In algae species with up to 50% oil content, the remaining biomass fraction also contains valuable chemicals or molecular compounds, which can be co-generated. Thus, biofuel production from algae biomass cannot be commercially feasible unless the by-products are optimally utilised. Hence, the production process and elimination of waste are crucial. The concept of biofuel refineries is to use each fraction of the biomass raw material to provide useful products and helps to scale back overall cost.

Effects of algae oil methyl esters on engine characteristics

Few research papers are available on the use of algae biofuel blends as fuels for internal combustion engines. The present study reviewed the objective and outcomes of using algae biofuel blends as fuels for IC engines. Many studies have reported that the quality of algae oil methyl esters and their mixture with diesel fuel complied with established fuel requirements and the engine operated smoothly without any major problems. Algae biofuel has a higher density and viscosity along with lower calorific value and cetane number; consequently, the use of algae biofuel results in higher fuel consumption and a slightly lower thermal efficiency than that of diesel. Thus, several studies, have reported that biofuel blends (up to 30%) are suitable for obtaining a high performance and low emission with IC engines [10-16].

The power and torque output of the IC engine decreased with an increase in the percentage of algae biofuel in the blends (approximately 6% decrease for BD100). This decrease can be attributed to the incomplete combustion of fuel due to a low cetane number [10, 11]. The heat release rate signifies the net energy liberated as heat throughout combustion; thus, it becomes a crucial parameter for assessing the suitability of a fuel for an IC engine. Most researchers have reported that the overall combustion characteristics of algae biofuel were quite similar to those of diesel, except for the slightly inferior in-cylinder pressure and heat release rates of algae oil methyl ester because it has a lower calorific value and higher viscosity than diesel. Moreover, the brake mean effective pressure obtained with algae biofuel blends did not vary by more than 3% from that obtained with diesel [9, 13].

Table 2. Summary of research on engine characteristics with algae biofuel as engine fuel.

Biofuel feedstock	Ref. Fuel	Engine type	Operating condition	Research Outcomes/results	Ref.
Algae oil (A. braunii sp.)	Diesel	1-cylinder, VCR, IDI, NA	Different engine speeds, CR and injection timing	Higher CP, HRR and Ignition Delay. Improvement in results by retarding injection timing.	[10]
Algae oil	Diesel	4-cylinder, DI, NA	Different engine speeds and blends ratio	Decrease in power and torque output with increase in blend ratio. Overall decrease in CO and NOx emission values.	[5]
Algae oil (C. cohnii sp.)	Diesel and BD20WCO	4-cylinder, Turbocharged CRDI	Different loading conditions and blends ratio	Increase in BSFC, NOx and ignition delay. Decrease in CP, BTE, HC and output torque. HRR remains unchanged.	[9]
Algae oil	Diesel	1-cylinder, air - cooled, NA	Different loading condition, blends ratio and injection timing	Advanced fuel injection timing improves combustion and performance with minimal emission.	[11]
Algae oil	Diesel	4-cylinder, DI, Water cooled, NA	Different loading conditions and blends ratio with additives	Slightly lower power and torque output but improvement in emission values.	[12]
Algae oil	Diesel and Rice bran oil	1-cylinder, Air cooled, NA	Different loading conditions and injection timings	Increase in BSFC and NOx Decrease in BTE, CO, HC and smoke. Advancing injection timing improved the performance of the engine.	[13]
Algae oil (Entromorpha sp.)	Diesel	1-cylinder, DI, Water cooled, NA	Different loading conditions and blends ratio	BD 20 shows better performance and emission characteristics. NOx emission increases up to part load but gradually decreases thereafter for all blends.	[14]
Algae oil (Chlorella sp.)	Diesel and BD30RME	3-cylinder, DI, NA	Different loading conditions and blends ratio	NOx emission remains unchanged for all blends. Increases in BTE along with the decrease in HC and CO emission.	[15]
Algae oil (Botryococcus braunii sp.)	Diesel	Single cylinder, air-cooled, DI, diesel engine	Different loading conditions with TiO_2 and SiO_2 nano additive blends	Improvement in calorific value and BTE with decrease in BSFC. Decrease in ignition delay time with HC and CO emissions.	[16]

[NA= Naturally Aspirated, DI= Direct Injection, IDI= Indirect Injection, BTE= Brake Thermal Efficiency, BSFC= Brake Specific Fuel Consumption, HC= Hydrocarbon, CO= Carbon Monoxide, NOx= Oxides of Nitrogen, CP= Combustion Pressure, HRR= Heat Release Rate, CRDI= Common Rail Direct Injection]

Due to an optimal combination of oxygenated nature and higher unsaturated fatty acids of algae biofuel, the presence of such excess oxygen molecules facilitates the complete combustion of fuel and reduces the level of undesirable emission. Thus, a drastic reduction in HC and CO emissions were noted with algae biofuel blends. Although most researchers have reported an increasing trend in NOx emission while using algae biofuel [9,11], some have also found relatively low or similar NOx emission levels [14,15]. However, the NOx values can be reduced by adding n-butanol to the blends [12].

Conclusion

Algae can potentially be used in the near future for the commercial large-scale production of biofuels through an economically effective, technically feasible, and eco-friendly process to supply fuel for transport. A review of the available literature reveals that compared with available biofuel feedstock, the major advantages of using algae-based feedstock are that they grow rapidly throughout the year, easily adapt to growth conditions and have superior efficiency also produced a high yield although they require relatively low attention and exhibit low resource consumption. Currently, the global energy crisis coupled with technological advancements such as hybrid biofuel refinery, innovative genetic, and metabolic engineering and improved cultivation techniques, have made algae biofuel a highly appealing and suitable alternative source of engine fuel.

Many studies have reported that algae biofuel blends can be efficiently used as alternative, renewable, and ecofriendly fuels without any major modification to the existing IC engine. Algae biofuel has a higher density and viscosity along with lower calorific value and cetane number than diesel; hence, the use of algae biofuel results in higher fuel consumption and slightly lower thermal efficiency than that of diesel. Algae biofuel contains an optimal combination of oxygenated and higher unsaturated fatty acids. The presence of such excess oxygen molecules facilitates complete combustion of the fuel and reduces the level of undesirable emission. Thus, from several studies, it can be inferred that biofuel blends (up to 30%) are suitable for improving engine performance and emission characteristics.

Furthermore, research on several new combustion technologies with emission control methods of modern diesel engines is warranted for the comprehensive optimization of combustion and emission. Moreover, the current need is to establish models that accurately correlate the engine operating variables and combustion-emission characteristics of algae biofuels with a minimal number of input parameters.

Refeerences

[1] Demirbas A. (2010) Use of algae as biofuel sources. Energy conversion and management, 51, 2738-2749.

[2] A Kleinova et al. (2012) Biofuels from algae. Procedia Engineering, 42, 231 – 238.

[3] Singh J and Gu S. (2010) Commercialization potential of microalgae for biofuels production. Renewable and sustainable energy reviews, 14, 2596-2610.

[4] P. Schlagermann et al. (2012) Composition of algal oil and its potential as biofuel. Journal of combustion, 1-14.

[5] G Tuccar and K Aydin. (2013) Evaluation of methyl ester of microalgae oil as fuel in a diesel engine. Fuel, 112, 203-207.

[6] EsraSorguven and Mustafa Ozilgen. (2010) Thermodynamic assessment of algal biodiesel utilization. Renewable Energy, 35, 1956-1966.

[7] Islam M A Ayoko G A Brown R Stuart D and Heimann K. (2013) Influence of fatty acid structure on fuel properties of algae derived biodiesel. Procedia Engineering, 56, 591-596.

[8] Chisti Y. (2007) Biodiesel from microalgae. Biotechnology Advances, 25, 294-306.

[9] Islam M A Rahman M M Heimann K and Ristovski Z D. (2015) Combustion analysis of microalgae methyl ester in a common rail direct injection diesel engine. Fuel, 143, 351-360.

[10] Haik Y Selim M and Abdulrehman T. (2011) Combustion of algae oil methyl ester in an indirect injection diesel engine. Energy, 36, 1827-1835

.
[11] V Hariram and G Mohan kumar. (2012) The effect of injection timing on combustion, performance and emission parameters with AOME blends as a fuel for compression ignition engine. Research journal of applied sciences, 7, 510-519.

[12] G Tuccar T Ozgur A Yasar and K Aydin. (2014) Experimental investigation of engine performance and emission characteristics of a diesel engine using blends containing microalgae biodiesel, n-butanol and diesel fuel. International conference on geological and environmental sciences, 73, 25-29.

[13] Jayaprabakar J et al. (2015) Experimental investigation on the performance and emission characteristics of a CI engine with rice bran and microalgae biodiesel blends. Journal of chemical and pharmaceutical sciences, 7
.
[14] R Velappan and S Sivaprakasam. (2014) Investigation of single cylinder diesel engine using biodiesel from marine algae. International journal of innovative science, engineering & technology, 1.

[15] Makareviciene V Lebedevas S Rapalis P and Skorupskaite V. (2014) Performance and emission characteristics of diesel fuel containing microalgae oil methyl ester. Fuel, 120, 233-239.

[16] S Karthikeyan and A Prathima. (2017) Environmental effect of CI engine using microalgae methyl ester with doped nano additives. Transportation Research, Part D, 50, 385–396.