Fuel 349 (2023) 128744

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Technical insights of microalgae derived bio-diesel on its performance and emission characteristics, techno-economics and practicability huddles

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ARTICLE INFO

Keywords:
Microalgae
Biodiesel
Internal Combustion Engine
Economics

ABSTRACT

Due to the growing awareness of the depletion of fossil fuels, biodiesel production has attracted a lot of interest recently. Since microalgae grow quickly and produce more oil than traditional biodiesel feedstock, they are attractive candidates for biodiesel feedstock. The productivity and oil content of microalgae have been targeted for improvement. Microalgae biomass has gained interest based on the characteristics of microalgae and its ability to overcome the harsh environment as well as its high efficiency on photosynthesis. Knowingly, the microalgae oil qualifies as prospective feedstock oil is crucial to understanding the potential of microalgae for biodiesel synthesis. Algal based biodiesel production has an importance on carbon- neutral source of transportation fuel. The present review focuses on the characteristics of microalgae oil biodiesel's qualities on the engine performance, combustion, and emission. Additionally, discussions on the techno-economic analysis and viability of employing this fuel in compression ignition engines are also made. Finally, the future direction is explained based on the facts derived from the study.

1. Introduction

There is shortage in availability of oil crops for biodiesel production. Finding a new feedstock that can be used to make biodiesel is crucial, but it must also be done without depleting the supply of edible vegetable oil. Algae are one of the better substitutes for the traditional biodiesel source [6]. Microalgae have drawn a lot of attention in the modern era because of their quick growth and robust life. It is suitable for the esterification or transesterification process to make biodiesel because of its oil content [68]. An affordable and environmentally favourable source of biodiesel is algae. The biomass used to make biodiesel is renewable and sustainable. One of the effective approaches is widely acknowledged to be the production of biodiesel from algal biomass. They are currently discussing alternative energy sources for oil that might supply all of the world's transportation energy requirements. The usage of algae fuel technology can help to reduce the greenhouse gas emissions that are typically produced by fossil fuel power plants and other carbon-intensive industrial sectors.

As per the International Energy Agency, the prosperous utilization of renewable energy resources have been exceeded the non– renewable energy source right from 2015 itself. Presently, in the current generation the biomass is targeted as an efficient renewable energy sources. Many products and energy sources have been derived and continuously attempted till now. Presently, production of fossil fuels from the algal biomass as gained more attention than earlier. The term biomass is categorized into first, second and third generation biomass. Of which, first generation biomass includes sugarcane, corn starch, barley etc; Second generation biomass includes lignocellulosic biomass such as wood chips, domestic solid wates, forest remains and the third-generation biomass includes algal biomass. Algae biomass is a unicellular and multicellular organisms which comes under prokaryotic and eukaryotic organisms. The reason behind the choice of choosing the third generation biomass is due the presence of high lipid accumulation of about 60–70% which results in the production of biodiesel. Although the.

Microalgae biomass is utilized in the renewable energy sector, it is capable to substitute as an alternative to the conventional fuel but the venturing of microalgae-based fossil fuels seems to be unsuccessful due

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https://doi.org/10.1016/j.fuel.2023.128744
Received 12 October 2022; Received in revised form 19 April 2023; Accepted 17 May 2023

to its undesirable returns on the investment. Therefore, it seems to be critical during the evaluation of its feasibility of microalgae-based supply chain and its assurance towards the long-term sustainability of microalgae conversion process.

In the present review paper is discussed with approaches, cultivation, methodology utilized in performing the techno-economic analysis of microalgae-based supply chain has been well discussed. The benefits of using microalgae for biodiesel in terms of its engine characteristics, growth and harvesting, types of microalgae (heterotrophic and autotrophic) could be used, the process (from strain isolation to biodiesel formed), biodiesel production from microalgae and the factors responsible to impact the process. Along with these, the feasibility analysis, which discusses the environmental benefit and cost-affordability, is also included. The present study examined each of these facts as well as potential future developments.

2. Microalgae

Microalgae are single cellular organisms that can be found in freshwater and saltwater. With over 25,000 species already isolated and characterised, they can be categorised as either prokaryotic *Cyanobacteria* (blue-green algae) or eukaryotic microorganisms. The photosynthesis carried out by these microbes is a crucial natural mechanism to reduce the atmospheric CO_2 concentration [70]. Microalgae or microphytes are microscopic algae invisible to the naked eye. Microalgae are distinguished by a quick generation time and an exponential growth rate in environments that are favourable to them. Microalgae are categorised into four groups. The diatoms, blue-green, green, and golden algae are among these.

The Fig. 1 depicts the oil yield/acre for different biodiesel sources. It clearly indicates that compared to the regular biodiesel sources the algae yield is enormously higher. Even the known biodiesel sources like soybean, sunflower and palm could produce almost 20times lesser oil than the microalgae.

2.1. Microalgae based products

Since these microorganisms exhibit a variety of metabolic diversities, microalgae are highlighted from a biotechnological perspective. Microalgae biomass is regarded as a promising source for the production of a number of bioproducts in this respect, in addition to its use in environmental processes. Microalgae have the capacity to supply the next level of lipids or carbohydrates for the production of biofuels. These microalgae are frequently used to produce both liquid and gaseous biofuels, such as butanol, ethanol, methane, and hydrogen. Microalgae are grown using the generated CO_2 to store carbohydrates. After fermenting the resulting microalgal biomass, which is rich in carbohydrates, bioethanol can be produced [17].Microalgae are a newly discovered form of renewable energy derived from living things. They are valued for their high energy content and have a significant potential to gain market share. The main barrier to reliable biorefinery operation is cultivation since microalgae development is highly dependent on environmental factors, particularly ambient temperature and solar exposure.

For the best solution, a total annual margin of 815,716 US dollars and 37.12 billion metric tonnes of CO_2 of greenhouse gas emissions is reported in the year 2021.The advantages feature of biofuels produced from biomass are renewability and a significantly smaller contribution to environmental pollution and global warming. The biggest contributor to global warming is the release of greenhouse gases, primarily CO_2 from the burning of fossil fuels. With a cumulative release of 35.3 billion tonnes of CO_2 to date, fossil fuels are to blame for 29 gigatons of CO_2 every year. While petroleum-based fuels have nil oxygen levels and substantial sulphur emission, biofuels, especially biodiesel, have oxygen levels of 10–45% and very low levels of sulphur emission. Biofuels are a clean, local, affordable, sustainable, and dependable fuel made from renewable resources. Fuels made from microalgae have a high potential to reduce global CO_2 emissions and are environmentally safe and nontoxic.1.83 kg of CO_2 can be fixed by 1 kg of algal biomass, according to reports. Additionally, in addition to CO_2, certain species utilise SOx and NOx as nutrient flows also it is estimated that 50% of the dry weight of algal biomass is made up of CO_2 [61]).

Microalgae are superior to terrestrial plants because of its higher photosynthetic efficiency and the capable to harvest more solar energy and carbon dioxide concentration. Using high-throughput technologies, strains, which are single-celled organisms that divide to produce additional cells, can be generated quickly. This could speed up processes in algae that would often take years in crop plants. Compared to terrestrial biomass used to produce biofuels, algae have less of an impact on the environment. Being one of the most Anaerobic digestions is a method for recycling nutrients in algal ponds. Even though the majority of the nutrients are kept in a bacterial slurry that can be degraded and used as an algal fertiliser, this bacterial process still results in the production of methane gas. Methane gas, despite not currently being a substantial resource, may assist in powering algae farms, and the low cost of anaerobic digestion will prevent the production of some higher-value proteins in the algae. Finding a balance between high-value co-products and effective anaerobic digestion is therefore crucial (Hannon et al., 2010). The permissible energy sources of the future will be biofuels made from sustainable and renewable feedstocks in place of fossil liquid fuels. Currently, bioethanol is the most widely used biofuel and is mostly made from the sugars of corn and sugarcane, but as technology advances, algal carbohydrates are being considered as viable raw materials for bioethanol production. Within a few years, the production of

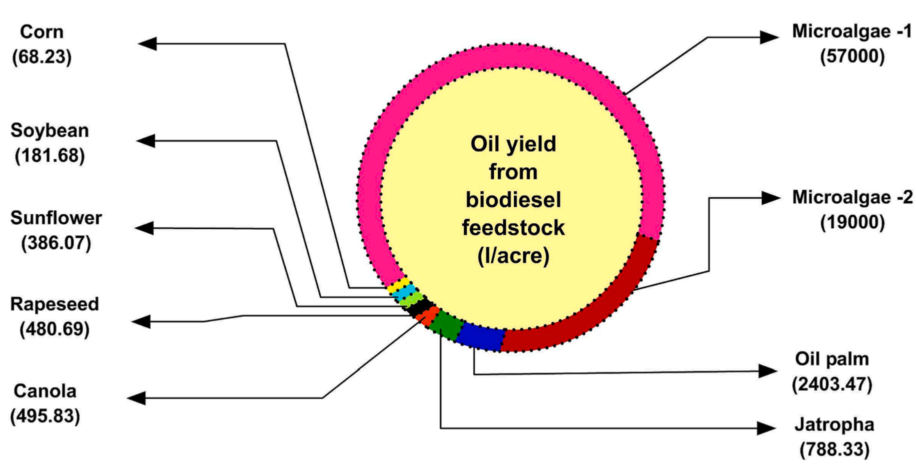

Fig. 1. Oil yield from various feedstock's.

bioethanol expanded significantly from 1 billion to 39 billion litres, and it will eventually reach 100 billion. Microalgae include significant concentrations of several carbohydrates, including starch, glycogen, agar, and cellulose, which are easily converted to fermentable sugars for the manufacture of bioethanol. It shows microalgae species rich in carbohydrates that can be used to produce ethanol from algae [37].

The rich biomolecules with economic and biological value found in microalgae species are a result of the enormous taxonomic and inherent biochemical diversity among these species. In order to manufacture biomolecules including lipids, proteins, and carbohydrates, microalgae are frequently employed. In addition to producing secondary metabolites, microalgae have a wide range of applications in nutraceuticals, drugs, dietary supplements, and personal care products. Additionally used for concurrent wastewater treatment, CO_2 sequestration, and biomass generation for high volume, low value products. Due to the high lipid content of microalgae (20–70% of dry cell weight), several start-up businesses in the clean energy production industry have made attempts to commercialise microalgae-derived biofuels in recent years [54]. Through dark fermentation and photo fermentation, it is also feasible to directly synthesise hydrogen from algae. Methane can be produced anaerobically from algae. It can be related to further steps (using the residue after lipids are removed, for example). One challenge is the high protein concentration of biomass, which could lead to NH_3 inhibition. By simultaneously digesting high carbon co-substrates, this issue can be resolved [53].

2.2. Algae cultivation and harvesting

Algae, which grows in a variety of bodies of water, including lakes, rivers, and the ocean, is an example of a photosynthetic autotrophs. They are responsible for creating atmospheric oxygen through a process known as photosynthesis, which converts carbon dioxide and water into carbohydrates. Simple prokaryotic single-celled *Cyanobacteria* to more complex multicellular eukaryotic algae are among the diverse and abundant phyla of algae [21]).

Microalgae are one way to get over the problems with their commercial use, such as their low cell density and difficult harvesting, by increasing their pace of development. Over time, a variety of tools and technologies have been developed to increase microalgae output[69]). Although microalgae can be easily cultivated in a lab setting with strict controls, it is still more difficult to guarantee their high productivity when producing on a wide scale. Fig. 2 depicts the important elements controlling microalgae growth. It influences algal development in the same way as culture media influences biological mechanisms, and light influences the growth of spectrum intensities. The tolerance and optimal carbon dioxide concentration is strain dependent. Most of the microalgae species grow well at 2% carbon dioxide but when the percentage of carbon dioxide concentration goes to above the level of 5% will results in inhibition of their growth. Therefore, it prevents the cell division of microalgae at higher concentration of carbon dioxide reported by [63].

The following qualities of an optimal microalgae cultivating system should be ensured for its adequate light source, effective transfer of material across liquid–gas barrier, simple operation procedure, minimal contamination rate, cheap overall building and production cost, and highland efficiency.

The open pond and photobioreactor are the two basic categories into which microalgae cultivating systems can be divided. Each method has its own benefits and drawbacks.

2.2.1. Open pond

Open pond farming is one of the earliest and most fundamental techniques for large microalgae culture. Open ponds are frequently used in the industry because of how much less expensive they are to build, maintain, and run. Other advantages of an open pond system are its easy setup, low maintenance needs, and ease of extension. The specific benefits and drawbacks of microalgae growing in open ponds and photo bioreactors are displayed in Table 1. Microalgae cultivation in open ponds will be preferable to photo-bioreactors for use in biofuels since it can produce large amounts of biomass with less upkeep. In the open raceway pond, the harvesting of *Tetraselmis* sp. *M8* microalgae cells grown in f/2 medium took place on 13th, 23rd, and 33rd days of cultivation periods. On the 13th day of harvesting of microalgae cells, the density of microalgae biomass found to be 2×10^6 cells/ ml; on the 23rd day of harvesting, the cell density was found to be 2.3×10^6 cells/ ml; and on the 33rd day of harvesting of microalgae cells, the density of microalgae biomass was found to be 2.8×10^6 Cells/ml [64].

2.2.2. Photo bioreactor

In order to grow phototrophs like microalgae in a closed system that forbids direct material exchange between the culture and its surroundings, a photo bioreactor is a form of bioreactor. For the use of biofuels, microalgae cultivation in open ponds will be superior to photo bioreactors. There are several issues that open pond culture design commonly encounters that a photo bioreactor can avoid. The photobioreactor (PBR) is any cultivation system designed for cultivating

Fig. 2. The factors influencing microalgae growth.

Table 1
Comparison between open pond and photo bioreactor cultivation.

Cultivation mode	Mode of agitation (mixing)	Advantages	Limitations	References
Open Pond	Paddle wheel	Applicable for higher mass production. Less energy input. Ease of construction. Maintenance and cleaning is easy.	Needs huge land for cultivation. Ease of contamination. Uncontrolled conditions for mixing, carbon dioxide sequestration and light Evaporation of medium occurs. Not all strain can grow. Less mass transfer and biomass productivity. During rainy season it may leads to overflow or need to be covered in prior.	[5]
Photo bio-reactor	Airlift and recirculation	Less energy input, operating cost and land requirement. Less chances for contamination Narrowed light path. Can be cultivated in outdoor and indoor conditions. Greater photosynthetic efficiency. Less hydrodynamic stress. Ease of use due to handy.	Scaling up and mass production consumes higher cost and land. Cleaning and wall attachment is tedious. Temperature maintenance is difficult High energy consumption when scaled up. Build with the help of sophisticated higher end materials. Photo-inhibition occurs at longer duration. Improper mixing.	[5]

photoautotrophic organisms using artificial light sources or solar light to aid photosynthesis, as illustrated in Fig. 3. Microalgae, Cyanobacteria, macroalgae, and certain mosses are frequently grown in PBRs. In fact, there are several types of photo bioreactors available: namely, open raceway pond, flat-plate photo bioreactor, inclined tubular photo bioreactor and horizontal tubular photo bioreactor. The tubular photo bioreactor (TPBR) consisted of a conical flask and a serpentine glass tube. First, the bioreactor makes better use of the available space than an open pond since it is smaller and more compact. A single strain, free of contamination microalgae culture is produced by the system as a result of the system's provision of a closed, strictly controlled environment for the culture's growth. In the closed photobioreactor, the *Tetraselmis* sp. *M8* microalgae biomass concentration grown in f/2 medium was initially found to be 1.2×10^6 cells/ ml at the time of cultivation and on the 8th day of cultivation, the biomass concentration was found to be 3×10^6 cells/ml [64].

Fig. 3. Schematic representation of tubular photobioreactor for the indoor cultivation of microalgae.

2.3. Harvesting of microalgae

Microalgae harvesting is a crucial stage in the processing of microalgae. According to a lot of studies, the high capital cost and energy need contribute for 20–30% of the total manufacturing cost. All harvesting techniques aim to remove as much culture media from the microalgae biomass as possible to facilitate processing that occurs after harvesting, such as the extraction of bioactive compounds. Numerous methods, such as filtering, centrifugation, flocculation, and flotation, have been used to extract biomass[66]. In the Filtration technique, A semi permeable membrane is used in the filtration process to hold onto microalgae while allowing liquid media to pass through, leaving the algal biomass behind to be collected [58]. Algae Harvesting and Separation Technologies.

Algae are frequently found in diluted concentrations in water, and recovering biomass from a diluted medium account for 20–30% of the total production cost. Algae harvesting techniques include sedimentation (gravity settling), membrane separation (micro/ultrafiltration), flocculation, flotation, and centrifugation. Sedimentation is the initial step in the process of clearing the water of algae. When the agitation is ended, the algae are allowed to settle and solidify. However, further strategies will probably also be applied for filtering include membrane separation [52].The literature survey on diverse biomass and its composition is elaborated in Table 2**.** Two correlation equations are used to calculate the higher heating value (HHV). The microalgae in open ponds were thought to be developed photo autotrophically, using

Table 2
Details of known algae biomass composition.

Algal species	Algae growth medium source	Elemental analysis (%) C	H	O	N	S	Proximate analysis (wt %) Moisture	Ash	Volatile solids	Reference
Nannochloropsis sp.	Aquarium water	48.41 ±0.05	9.01 ±0.21	33.91 ±0.04	7.38 ±0.06	1.29 ±0.15	4.10 ±0.23	8.28 ±0.04	82.28 ± 0.29	[19]
Chlorella sp.	Blue green-11 medium	54.34	8.04	32.12	2.5	–	72.36	2.99	-	[51]
Nannochloropsis sp.	Blue green-11 medium	62.51	9.24	19.85	1.76	–	64.05	6.65	-	[51]
Chlorella vulgaris	Aquaculture wastewater	29.26	3.78	28.26	−6.22	–	–	38.16	55.65	[57]
Chlorella vulgaris	Aquaculture wastewater	45.15	5.75	42.88	–	–	–	5.57	82.43	[57]
Nannochloropsissalina	F/2 culture medium	44.5 ± 0.2	7.3 ± 1.7	25.4 ± 1.9	9.5 ± 0.2	3.0 ± 0.6	–	–	-	[14]
Chlorella pyrenoidosa	BG-11 medium	22.90 ± 0.2	7.7	1.04	43.87	0.01	4.6	2.3	56.37	(Badiei et al., 2014)
Nannochloropsis gaditana	F/2 medium	47.6	7.5	21.9	6.9	0.87	1.4	2.5	57.1	(Kanda et al., 2015)
Chlorella sorokiniana	Blue green-11 medium	30.26	6.11	47.41	6.66	0.57	4.52	7.9	52.68	(Pandit et al., 2017)

sunlight as their energy source. Nutrients may be collected from the factory's boiling house, laboratory, or garage after they have undergone their initial treatment in the relevant primary treatment plant. The primary treatment facility could boost the pond's photosynthetic activity by reducing the effluent. On one side of the paddle wheel, the cultivation ponds would receive the algal broth from the PBRs and cycle it there. After development and circulation, the algal biomass needs to be harvested at the location on the opposite side of the paddle wheel [12]. Algal growth, lipid concentration and the primary characteristics are greatly depending on type of source, growth medium and nutrients supply.

3. Stress conditions on lipid accumulation

Microalgae are known to grow quickly and have the ability to store lipids inside their cells, making them a potential feedstock for the production of biodiesel. However, producing high lipid content and biomass at the same time is frequently difficult. *Chlorella vulgaris* was subjected to a stress environment such as nutrient deprivation, salinity, and light effect after harvesting to assess the impact on their lipid content [44]. These findings could be used to create microalgae-based biofuel. It has been demonstrated in numerous studies that changing the stress or growth circumstances can enhance the amount of lipids in microalgae. Temperature, pH, light intensity, nutrients, and salts are believed to be the primary environmental stresses that cause microalgae to accumulate more lipids [49].

Polar and neutral lipids can be divided into two classes. They are soluble in the majority of organic solvents but insoluble in water. Phospholipids and glycolipids are examples of polar lipids, whereas acyl glycerides (tri, di, and monoglycerides) and free fatty acids are examples of neutral lipids. Since polar lipids and an energy source are used to form cell membranes in microalgae, neutral lipids are used instead and the range for the amount of lipid per dry weight of microalgae is 1.5% to 75%. For instance, *Chlorella vulgaris's* lipid content ranges from 12% to 26% while *Botryococcus braunii's* ranges from 14% to 75% [15]. The use of combined nutrition and culture condition stress, microalgae-bacterial interactions, phytohormones, EDTA, and chemical additives, as well as improving light conditions utilising LED, dyes and paints, as well as gene expression analysis, are discussed as advanced methodologies. Recent developments in genetic engineering, metabolic engineering, and gene expression investigations have produced encouraging results for increasing lipid output in microalgae [55].The details of known algae biomass composition from different sources and Table 3. Elucidates composition, carbon source and primary characteristics of different algae species.

The process diagram for manufacturing biodiesel from algae is shown in Fig. 4. Algal growth, harvesting, dewatering, oil extraction, and Transesterification of algae oil to fatty acid methyl ester (FAME) or biodiesel are all processes in the process. A sustainable, biodegradable fuel made domestically from vegetable oils, animal fats, or used restaurant grease is called biodiesel. Biodiesel is one of the most promising renewable and sustainable fuels for automobiles since its combustion properties are equivalent to those of diesel produced from petroleum. The renewable Fuel Standard's biomass-based diesel and total advanced biofuel requirements are both satisfied by biodiesel. The existing environment, which includes a steadily increasing rate of petro-diesel depletion and ultimately related socioeconomic repercussions, strongly supports the creation of a suitable petro-diesel substitute. To look at even more plausible and prospective answers, extensive field-work has already been done and is still being done.

4. Biodiesel

Algal biomass can be converted into a biofuel using a number of techniques. In the study, microalgae with 30% oil content serve as a baseline signal that, for instance, if the microalgae are used only for the production of biodiesel, only 30% of the biomass will be used. It should be mentioned that since algae's properties were compatible with

Table 3
Composition, carbon source and primary characteristics of different algae species.

Algae	Carbon source	Cultivation medium	Biomass productivity (g/L d)	Specific growth (day^1)	Maximum biomass yield (g/L)	Reference
S. obliquus	CO_2	Urban wastewater	0.20	0.6	1.88	[4]
Chlorella sp.	CO_2	Blue green-1 medium	0.24	NA	NA 1.21	[45]
Chlorella sp.	Mollasses	Blue green-1 medium	0.02	0.03	0.84	[45]
Nannochloropsissalina	Glucose	Walnes medium	NA	NA	1.85	[41]
Chlorella sp.	Wine lees	Blue green-1 medium	0.35	NA	1.75	[5]

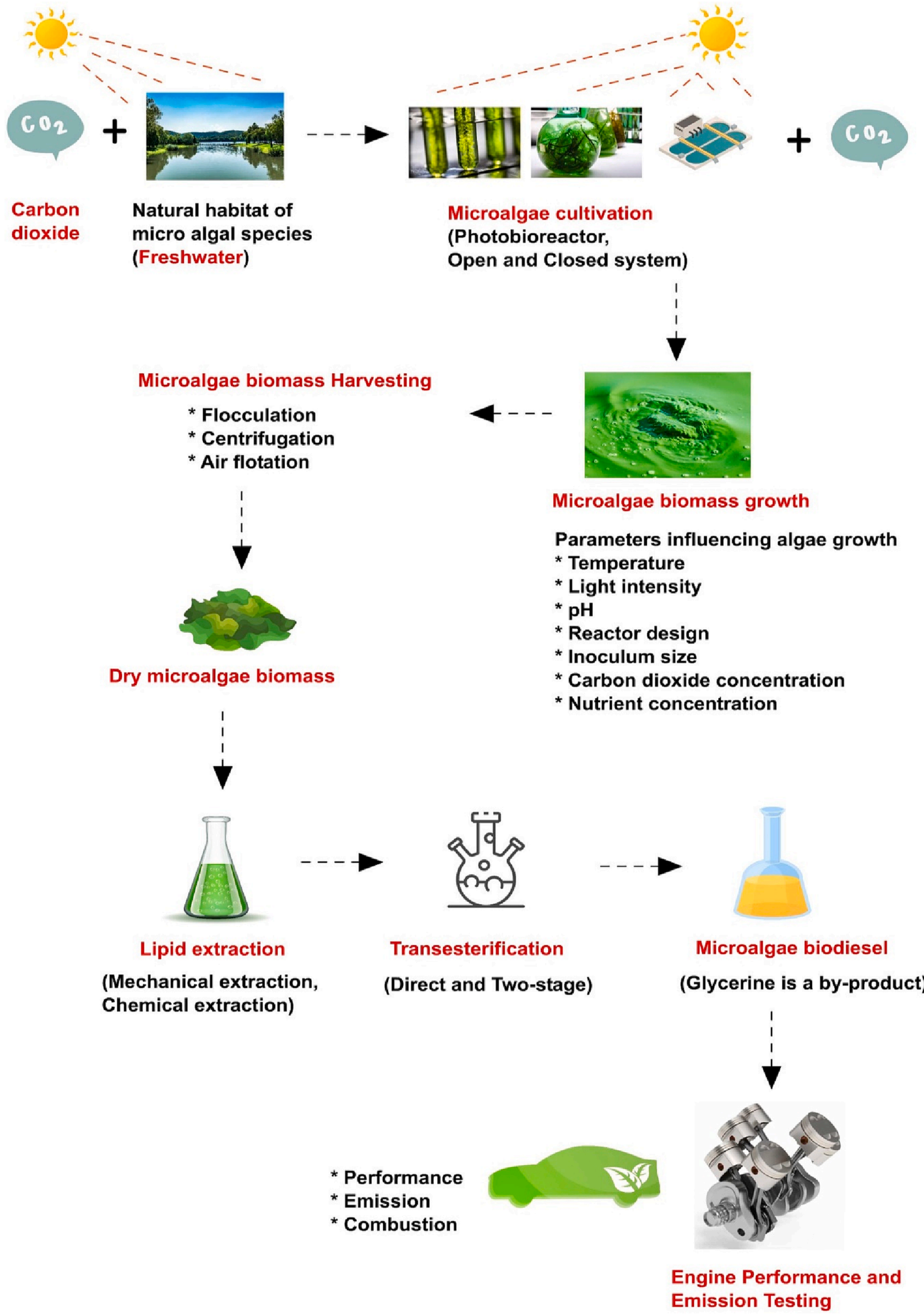

Fig. 4. Process diagram of producing biodiesel from algae.

petroleum diesel and their performance and emission standards were close to those of diesel, algae and its biodiesel and blends may be used as diesel engine fuel in present diesel engines without requiring any modifications. Examining the physiochemical characteristics of blends and how minute volumes of algae biodiesel blends affect compression ignition engines' performance and emissions is possible while also considering the state of the art review on this understudied topic and blend production[33]. The development of numerous microalgae bio-diesels and their application in IC engines has also been highlighted in many works.

To understand the current commercial situation of the microalgae biodiesel business, a techno-economic study was developed and demonstrated that closed-type reactors are effective for continuous culture due to the on-going management and availability of optimal growth materials. There will be certain limitations on the use of these microalgae as alternative fuels because of their lower yield per hectare, higher land consumption, shorter lifespan, and higher price. Algae are a wonderful choice for the production of biodiesel since they have higher biomass yields/day and per unit of cropping area. Utilizing raw algal oil can address problems associated with the use of pricy chemicals and procedures during the transesterification reaction required to produce bio-diesel. The recent study's goal was to determine whether or not algal biodiesel will eventually replace diesel (Dharma prabhakaran et al., 2020).

Algal oil production is higher than that of conventional oil seed crops due to the following factors:

(a) ability to grow year-round

(b) increased tolerance to high carbon dioxide content
(c) very low water consumption rate
(d) lack of need for herbicides or pesticides during growth
(e) Algal species have a very high development potential when compared to other species.

Saline, brackish, and coastal waters are harsh settings where algae can thrive but have no impact on conventional agriculture.

(f) they can employ a variety of wastewater sources that provide additional nutrients in addition to nitrogen and phosphorus
(g) Algal biomass has a number of drawbacks, too, including increased production costs when compared to traditional crops. Algae harvesting, like other energy-intensive processes, accounts for 20–30% of the total cost of manufacturing

The most recent research and cutting-edge advancements in algal biomass for enhanced biofuel production have been examined in some studies. One such study discussed the value of the contents of algal cells, various ways to produce goods utilising various conversion technologies, and their potential as a source of energy security in the future [11].

4.1. Transesterification process

According to the reaction at par, the most frequent method for producing methyl esters is transesterification of fats and oils. At atmospheric pressure and a temperature of roughly 60–70 °C, triglycerides are transesterified batch-by-batch or continuously in multistep reactors using excess methanol and an alkaline catalyst such sodium methylate or potassium hydroxide [50]. To avoid the formation of soap during the reaction, which the alkaline catalyst promotes, the moderate reaction conditions need the removal of free fatty acids from the oil through refining or pre-esterification prior to transesterification[69]). When the reaction is complete, the mixture is given time to settle [43].

The activity of the enzyme rises with temperature until denaturation takes place and activity falls. Conversion is accelerated with an increase in reaction temperature due to an increase in the initial reaction rate. However, conversion efficiency falls when an enzyme is overheated and denaturized by the process of esterification used in biodiesel facilities built for waste-based oils [43]. The process diagram for making biodiesel from algae is shown in Fig. 5.The process includes growing the algae, harvesting it, removing the water, extracting the oil, and then trans esterifying the oil into biodiesel or fatty acid methyl ester (FAME). The commercial production of microalgae biodiesel has been constrained by on-going technical difficulties. One of the major difficulties are huge water requirement, it ranges 300 to 2000 L/gallon of biodiesel range. Also, lipid extraction requires a lot of energy (Alok [67]. A number of acids are used to catalyse this reaction at moderate pressures and temperatures [22]. In spite of these shortcomings worldwide there are many ongoing algae oil plants are installed. The European Union (190 plants) is the largest producer, with 14 million litres of output and 21 billion litres of installed capacity. The second-largest producer is the USA. Argentina and Indonesia provide 9 and 7 billion litres of production, respectively, and Brazil comes in third with just over 50 plants, generating 5.4 billion litres but having an 8.4 billion litre capacity [24]. These data clearly show the interest on algae oil for biodiesel production globally.

4.2. Side streams – Glycerol, soap

When making biodiesel from an oil or fat containing a free fatty acid, such as oleic acid, the alkali catalyst that is usually employed to promote the synthesis will react with this acid to create soap. Because the catalyst is bound in a way that does not help speed up the reaction, this reaction is undesirable. A product's excessive soap content can prevent further biodiesel production steps like glycerol separation and water washing. Another issue is water in the fat or oil. In the presence of water, especially at high temperatures, the triglycerides can hydrolyze to create diglycerides and a free fatty acid. In the presence of an alkali catalyst, the free fatty acid will react to produce soap. Water usually causes the reaction to produce an excessive amount of soap when it is present. Due to the tendency of saturated fatty acid soaps to solidify at room temperature, an overabundance of soap in a reaction mixture can cause it to gel and create a semi-solid mass that is exceedingly challenging to remove. Soap and glycerol separation is a big task in the post biodiesel production. But these eventually have a great advantage is that, many valued products can be derived from the excessive soap and glycerol if properly removed or washed. It was discovered that glycerol from the biodiesel side stream is an affordable carbon source for the production of rhamnolipids (RLs), which may also aid in waste management. *Pseudomonas aeruginosa* RS6 was used in a study to produce RLs using waste glycerol as a substrate, and their physico-chemical properties were evaluated. During the fermentation process, various mono- and di-RL compositions were produced depending on the temperature, the pH of the starting medium, the amount of waste glycerol, the sources of nitrogen, and the concentrations [9].

5. Engines

An engine is used to convert one form of energy into another. Almost

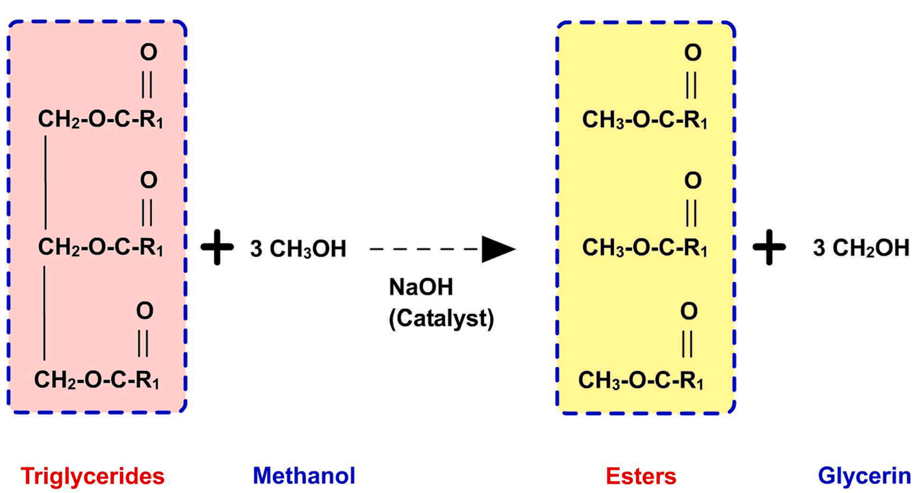

Fig. 5. Transesterification process.

all the engines convert heat energy in to mechanical energy; hence they are called as heat engines. An internal combustion engine (IC) is defined as a heat engine to which the heat energy is supplied by the combustion of fuel and converts that in to useful mechanical energy directly. IC engines have a long history to study about. Since the IC engine was invented and developed, it had greater impact on the socio-economic life of mankind. Internal combustion engines are treated as a safe power source for road, rail and off-highway vehicles, boats and ships. They are also used in electric generators of small units to huge capacity. The 4 S compression ignition (CI) engine is a more efficient and versatile one. CI engines are extensively used in the automobile sector for transportation and agricultural applications. Due to the energy sector's increasing reliance on fossil fuels like diesel, finding alternate sources to use as a fuel for transportation is essential. There are numerous studies already reported from almost all countries on using alternate fuels in diesel engines. Fuel vaporisation and heat transfer properties have an impact on fuel–air mixing in direct injection compression ignition (DICI) engines, which is also impacted by the FIP and SOI timings. These injection parameters have a major impact on the rate of pressure rise (ROPR) and heat release rate (HRR), both of which have an impact on the engine's ability to produce power and transmit heat. Therefore, optimising the fuel injection parameters is required to create effective and clean diesel engines [2]. Due to the considerably longer ignition delay experienced, advanced fuel injections demonstrated increased heat release rate (HRR), cylinder pressure, and rate of pressure rise (RoPR). 34° CA BTDC SOI had the lowest brake specific fuel consumption (BSFC). Advanced fuel injection timings for this newly developed CRDI system resulted in a reduction in engine exhaust emissions, with the exception of NOx [1]. Diesel engines can be reformulated with DMC, n-butanol, and sapota oil methyl ester to reduce emissions and use renewable fuel [29].

5.1. Common rail direct injection diesel engine

Particularly when used for agricultural and other heavy loads, a diesel engine will emit more PM pollutants and make a lot of noise. A single cylinder diesel engine was retrofitted with CRDi capability, and testing was carried out in CRDi mode at increased pressure. Table 4 lists the engine specifications. These issues can be solved by a CRDI engine since this technology only needs one fuel pump to operate numerous cylinders. Additionally, because the CRDI system decreases noise, smoke, and particulate matter, it is good for the environment. It produces a lot of power at low rpm. Fuel economy is the CRDI system's key benefit [65]. All of them are essential for a CI engine that runs on biodiesel. Today's manufacturers use CRDI technology to get around these drawbacks of conventional diesel engines, particularly in passenger vehicles, where they were often slow, noisy, and underwhelming in performance.

On the other hand, with electronic fuel injection systems, an electronic control unit (ECU) can easily and precisely control and adjust fuel injection parameters such as injection pressure, rate, multiple injections, and start of injection (SOI) under various engine operating conditions. Unit pump systems, unit injector systems, and CRDI systems are all types of electronic fuel injection systems utilised in contemporary diesel engines. In common rail direct injection, the main combustion chamber, which is housed in a cavity above the piston crown, is where the combustion occurs. The engine ECU, which receives input from several sensors, works in conjunction with the CRDI technology. The precise fuel dosage and injection timing are then calculated. The fuel system has parts that are more sophisticated in nature and electronically controls them. In addition, electronically powered solenoid injectors are used in place of the conventional injectors [27].

Table 4
Specifications of CRDi Diesel engine.

Parameters	Specifications	Reference
Type of Engine	Cylinder: 1 Stroke: 4	Alok Ranjan et al. (2017)
Injection pressure	600–1000 bar	
Cooling system	Water cooling	
Type of fuel used	Diesel/Biodiesel	
Rated power	5.2 kW at 1500 RPM	
Torque at full load	0.033 kg-m	
Cubic capacity	0.661 L	
Bore diameter	0.0875 *m*	
Stroke Length	0.11 *m*	
Ratio of Compression (RC)	17.5:1	

6. Engine performance parameters (biodiesel blends and pure)

Biodiesel, a byproduct of the transesterification reaction of fatty material, proves its positive impact on the reduction of exhaust emissions when used (even partially) to power compression-ignition engines.

The development of injection systems, which provides new control techniques, continues to advance, and despite the fact that many studies have focused on the production of biofuel and its use in combustion engines, the search for novel methods to enhance biofuel combustion is motivated by this development. Particularly, there hasn't been much research on the possible use of biofuels in modern CRDI (Common Rail Direct Injection) engines with divided injection technology. Additionally, there is a dearth of information on the performance and emissions of engines using biodiesel derived from algae [42]. The factors affecting in engine output is discussed in Fig. 6.

6.1. Technical insights into engine performance of algae biodiesel

The current state of affairs requires the creation of a more effective diesel engine fuel replacement due to rising fuel consumption, diesel fuel exhaustion, and the accompanying social and economic impacts. Therefore, potential alternatives to diesel are currently being investigated. In order to provide an efficient and effective alternative fuel, the internal combustion engines performance is essential. The current scenario calls for the development of a more effective diesel engine fuel replacement due to rising fuel use, the depletion of diesel fuel, and the ensuing social and economic implications. In this situation, internal combustion engine performance is essential for providing an effective and efficient alternative fuel. Third-generation fuels made from algae seem to hold promise for meeting our energy needs in the future. A10, A20, A30, A40, and A100 are diesel fuel blends incorporating algae that are made to work in diesel engines[56]. The B10 and B15 algal biofuel-diesel blends (10% and 15% of algae biofuel are combined with diesel on a volumetric basis) were taken into consideration. The fuel injection pressure (FIP), which was changed from 600 to 1050 bar in stages of 150 bar, was tested on a CRDI diesel engine running at a constant speed of 1500 rpm. The findings show that when compared to other injection pressures, brake thermal efficiency (BTE) is maximum and brake-specific fuel consumption (BSFC) is lowest at high fuel injection pressure, or 1050 bar.

The Table 5 depicts the detail of various engine performance parameters by varying the algae biodiesel diesel blends in diesel engines. In addition to blend preparation, physicochemical properties and the effect of algal biodiesel blends on compression ignition engine performance and emissions might be studied [34]. In order to predict certain parameters, including cylinder pressure, exhaust gas temperature, brake thermal efficiency, specific fuel consumption, and emissions of carbon dioxide, nitrogen oxide, and particulate matter at a constant engine speed under a condition of 100% load, s simulation study is normally conducted[48].Based on the researches published[7],the degree of agreement between the experimental and numerical results was determined to be sufficient. Several parameters, such as cylinder pressure, exhaust gas temperature, brake thermal efficiency, specific fuel consumption, and emissions of carbon dioxide, nitrogen oxide, and particulate matter at a constant engine speed under a condition of 100% load, were anticipated using simulation in that studies. Table.5 lists the types

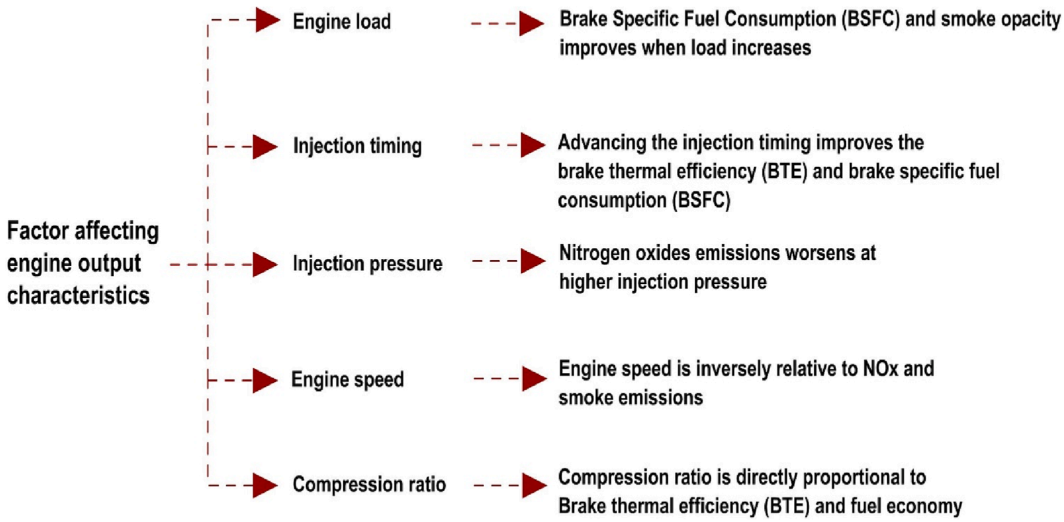

Fig. 6. Factors affecting in engine output.

Table 5
Performance of different algae biodiesel blends in diesel engines.

Microalgae species	Engine Condition	Engine details	Blends	Performance analysis compared to diesel fuel			Reference
				Torque (Nm)	BSFC (g/kWh)	BTE (%)/brake power (kW)	
Chlorella sp.	Varying power	3 cylinder, DI, 3300 CC, Max power = 30 kW @1500 rpm	B30 and Diesel	–	695 for B30661 for Diesel at low load 270 for B30-242for diesel at high load	Maximum: B30 – 36.2% D – 34.8%	[40]
Crypthecodiniumcohnii	Varying power	Four cylinder, 2000CC, max power = 100 kW at 4000 rpm, CR = 18, turbocharged	Diesel fuel, B10, B20, B50	–	Maximum: B50 – 305.4 D – 290.6 at lower loads, Decreases at high load	Maximum: B50 – 37.5% D – 38.2%	[28]
Nannochloropsis sp.	Varying speed	Single cylinder, Ricardo E6 IDI, max power = 14.0 kW, CR = 22, injection timing – 20–45° BTDC	Diesel fuel, B100, B50, Raw algae oil	Maximum @1800 rpm: B100 – 8.4 D – 10	–	–	[23]
Chlorella protothecoides	Varying speed	Single cylinder, 2190 CC, rated power 3.09 kW @3600 rpm, fuel injection 16.5° BTDC.	Diesel fuel, B20, B50, B100	@ low rpm: B100 – 11 D – 11.46 @high rpm: B100 –9.2 D – 10.7	@ low rpm: B100 – 393.5 D – 363.2 @ high rpm: B100 – 292.5 D – 260	@ low rpm: B100 – 24.2% D – 23% @ high rpm: B100 – 34.2% D – 34.9%	[3]
Chlorella vulgaris	Varying power	Kirloskar single cylinder, DI, 661 CC, max power = 3.5 kW, CR = 14:1 to 18:1	Diesel fuel, B10, B15, B20	–	–	Maximum: B20 –21.5% D – 20.1%	[47]
Neochloris oleoabundans	Varying engine load	Four cylinder, 2000CC, max power = 100 kW at 4000 rpm, CR = 18, turbocharged	Diesel fuel, B20	17.5 Compression ratio and 1500 rpm	5.19–9.5%	0.79 – 3.70%	Aman [75]
Bottryococcus braunii	Varying engine load	Single cylinder 3.5 kW diesel engine	ABD40, Diesel fuel	–	–	30.39%	Teku [76]
Scenedesmus obliquus	Varying engine load	Single cylinder 3.5 kW diesel engine	BD 50%, 50% Diesel	–	6.4%	7.1%	Medhat Elkelawy et a., 2021

of microalgae species, descriptions of the engines, testing parameters, engine performance metrics. Regardless of the type of microalgae used, most studies indicate that brake specific fuel consumption (BSFC) for microalgae-operated engines rises in comparison to diesel. Because algae biodiesel has a lower heating value than diesel, and has a higher density are the reasons. Additionally, it was clear that BSFC rises in proportion to the blending ratio. Pure biodiesel fuel has a lower brake thermal efficiency than other fuel types. BTE can be improved with lower blends up to B20 because better combustion is made possible by higher oxygen concentration compared to fossil fuel.

6.2. Technical insights into emission parameters

Multiple injections in association with suitable (High/heavy) exhaust gas recirculation (EGR) is a promising technique to achieve low temperature combustion (LTC) regime in modern CRDI (common rail direct injection) diesel engine. This helps for simultaneous reduction of NOx and Soot to meet the stringent emission norms without penalising the fuel efficiency and overcome the drawbacks of EGR-LTC. Most of the studies show that break specific fuel consumption (BSFC) for microalgae operated engine increases in comparison to diesel irrespective of microalgae type (Table 6). Thus, was attributed to higher density and lower heating value of the biodiesel as compared to the diesel. There are limited insights available which discuss about the potentiality of latest

Table 6
Emission parameters of different algae biodiesel blends in diesel engines.

Microalgae species	Engine Condition	Engine details	Blends	Exhaust emissions compared to diesel fuel HC	CO	Smoke	NOx	Reference
Chlorella protothecoides	Varying speed	Single cylinder, 2190 CC, rated power 3.09 kW @3600 rpm, fuel injection 16.5° BTDC.	Diesel fuel, B20, B50, B100	_	@ low rpm: B100 – 3.92% D – 4.49% @ high rpm: B100 – 0.13% D – 0.58%	_	@ low rpm: B100 – 393 ppm D – 426 ppm @ high rpm: B100 – 480 ppm D – 559 ppm	[3]
Nannochloropsis sp.	Varying speed	Single cylinder, Ricardo E6 IDI, max power = 14.0 kW, CR = 22, injection timing – 20–45° BTDC	Diesel fuel, B100, B50, Raw algae oil	_	_	_	_	[23]
Crypthecodiniumcohnii	Varying power	Four cylinder, 2000 CC, max power = 100 kW at 4000 rpm, CR = 18,turbocharged	Diesel fuel, B10, B20, B50	Maximum: B50 – 4.7 g/ kWh D – 9.65 g/ kWh	_	_	Maximum: B50 – 4.8 g/ kWh D – 3.92 g/ kWh	[28]
Chlorella vulgaris	Varying power	Kirloskar single cylinder, DI, 661 CC, max power = 3.5 kW, CR = 14:1 to 18:1	Diesel fuel, B10, B15, B20	Maximum: B20 – 61.3 ppm D – 88.1 ppm	Maximum: B20 – 2,4% D – 2.7%	Maximum: B20 – 81.3% D – 97.6%	Maximum: B20 – 1094.2 ppm D – 1029.7 ppm	[47]
Chlorella sp.	Varying power	Three cylinder, DI, 3300 CC, Max power = 30 kW @1500 rpm	Diesel fuel, B30	Maximum: B30–290.8 ppm D – 328.4 ppm	Maximum: B30 – 194.7 ppm D – 209.6 ppm	Maximum: K value B30–0.15 D – 0.31	@ Max 1200 rpm: B100 – 1089 ppm D – 848 ppm	[40]
Neochloris oleoabundans	Varying engine load	Four cylinder, 2000CC, max power = 100 kW at 4000 rpm, CR = 18, turbocharged	Diesel fuel, B20		5.19–9.5%		22.67 – 70.69%	Aman [75]
Bottryococcus braunii	Varying engine load	Single cylinder 3.5 kW diesel engine	ABD40, Diesel fuel	70.53%	25.51%	14.85%	12.81%	Teku [76]
Scenedesmus obliquus	Varying engine load	Single cylinder 3.5 kW diesel engine	BD 50%, 50% Diesel	7.2%	17.35%	17.35%	9.5%	Medhat Elkelawy et al., 2020

Quadruple injection (early-pilot-main-post/after; epMa) strategy in combination with high EGR and different injection timing over triple injections (pilot-main-after; pMa) at wide operating conditions [5]. Minor engine calibration adjustments were made to apply the quadruple injection approach, and the primary injection timing was modified to simplify the system [13].When biodiesel is utilised, the emission of carbon monoxide is often lower due to efficient burning. Some of the CO that is produced absorbs extra oxygen from the biodiesel fuel and turns into CO_2. All of the researches in Table.6 and Fig. 7 are the supporting documents from the literature. The development of the unburned hydrocarbon (HC) molecules was either caused by an excessively lean air/fuel mixture or by the formation of a fuel over rich zone. In the case of biodiesel, the fuel mixture is oxidised by oxygen bound to the fuel, resulting in complete combustion and lower HC emissions. Consequently, microalgae biodiesel generally has lower HC emissions than diesel fuel. The strict emission requirements enforced by emission regulating organisations have recently given nitric oxide emissions top priority. When compared to fossil diesel, NOx emissions often rise with biodiesel fuel. This rise may be caused by increased cylinder temperature, oxygen availability, and residence time. Most research on microalgal biodiesel indicated greater NOx emissions. They also pointed, the higher cetane number of biodiesel as a potential explanation for the aforementioned behaviour. Additionally, they saw a drop in the peak pressure for biodiesel fuel. Due to fuel-bound oxygen assisting in improved combustion, microalgae biodiesel fuel is used in diesel engines less frequently than diesel fuel in terms of smoke emissions.

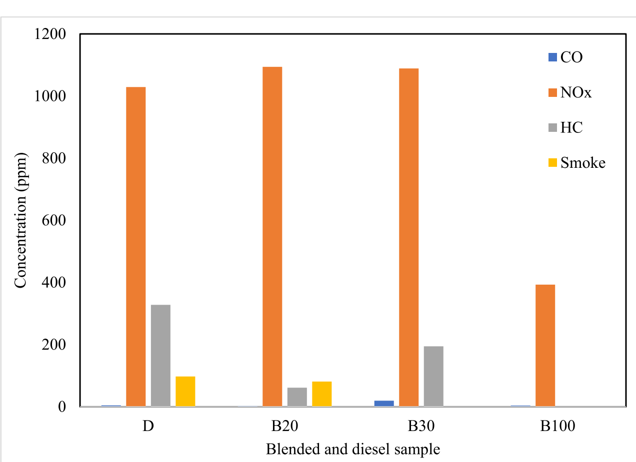

Fig. 7. Performance of different algae biodiesel blends in diesel engines.

6.3. Technical insights into combustion parameters

It clearly illustrates that peak pressure rises as the applied load rises. As a result, the amount of fuel injected increases. The fuel contains more carbon particles, which raises the calorific value of the fuel and causes the peak pressure to rise. Peak pressure obtained for all loads was nearly identical for diesel and biodiesel. When compared to blended diesel, the peak pressure of diesel is only roughly 3 to 11% greater. The fundamental reason for the minor difference is that, as previously stated, biodiesel has a higher viscosity and a lower calorific value. The heat release parameter primarily represents the chemical energy present in the fuel. It is crystal evident from the graph that HRR rises as applied load rises. In the current scenario happens because as the load is raised; the amount of fuel injected increases as well, resulting in higher carbon particle content in the fuel. More fuel particles enhance the fuel's energy content, which raises HRR. Additionally, a trend analysis demonstrates that when compared to diesel, biodiesel blends exhibit greater or nearly same HRR. Because biodiesel and its blends take longer to ignite due to the fuel's high viscosity and lower calorific value. When compared to pure diesel, an increase in ignition delay shortens the pre-mixed combustion phase's duration and increases diffusion combustion phase. The primary cause is that larger applied loads appear to cause higher cylinder temperatures, which in turn heightens oxidation reactions. Further reducing the biodiesel's ignition delay is the fact that viscosity also lowers at higher temperatures. In the end, it was determined that, when compared to diesel, the HRR variation for algae and its mixes was most similar to 15%. Algae mixes are more likely to replace diesel fuel and slow down the depletion of fossil fuel [30]Table 7 show the variation of Heat release Rate in kJ/m3°and pressure in bar against Crank angle for diesel.

7. Factors influencing performance, emission and combustion

Many researchers have looked into the efficiency, emissions, and combustion properties of diesel engines running on edible and non-edible biodiesel fuels utilising variables including engine load, speed, excess air ratio, equivalency ratio, and fuel oxygen. When describing the combustion properties of an internal combustion engine, the ignition delay duration is a crucial quantity. It is the difference between the commencement of combustion and the start of injection (SoC). From the review it is very evident that algal biofuels play a large contribution in lowering unburned hydrocarbon, CO, CO_2, NOx, soot particles, and particulate matter. Effective combustion and thermal performance are also positively impacted. Cetane number, latent heat, and the fuel's ability to self-ignite are all factors that affect ignition delay. The engine's ability to transform chemical energy into meaningful work is measured by the brake thermal efficiency (BTE), a dependable parameter. Oxides of nitrogen (NOx) emissions are primarily caused by the reaction time, local air–fuel ratio, and temperature in the burned mixture. As like other conventional biodiesels algae derived biodiesel also posed greater NOx emissions due to its higher oxygen content and greater retention time for combustion. However, adding cetane improvers and other metal and other bio additives may try to overcome this problem. Slight engine modifications like altering the injection pressure, timing, compression ratio are also considered to be suitable in reducing the NOx emissions. Specific NOx reduction techniques like Exhaust gas recirciulation or emulsification may also be tried. but still how for it will hold good inn long run is a big question. However, the other carbon associated emissions are on par with the regular biodiesel types and smoke from the diesel engine also quite within the limits.

8. Techno-economic assessment (TEA)

The techno economic assessment of the routes is essential in order to know the economic viability in these biorefinery approaches. Microalgae are grown, harvested, made into lipids, and turned into biodiesel as part of the biorefinery process [16]. The price of producing one tonne of algae can range from $150(Rs.12,356) to$6,000(Rs.4,94,265) depending on the methods and assumptions used [60].Open pond systems (OP), flat panel photobioreactors, vertical photobioreactors, and horizontal photobioreactors were the main technologies employed in microalgae farming. When opposed to an open system, a closed system requires more money to operate [26 10].The selling price of $8.52 (Rs.701.85) and $18.10/gal(Rs.1,491) of triglycerides in open pond and photobioreactors respectively allowed for the 10% rate of return [18]. The poor biomass productivity of bubble column PBRs is regarded as the priciest biofuel production technology.

The number of reactors needed and the cost of the raw materials are reduced by the tubular PBRs system's higher biomass at lower cost. For mass production, the open pond cultivation approach was less expensive, but the biomass productivity is lower with a higher need for water, increasing the running cost [20]. Due to the enormous amount of water evacuated, the dewatering step for open pond systems has higher running costs. A rough estimate of the overall cost is shown by the open pond with low biomass output at 45.73 %[36]. Since the cost of investment for photobioreactors was four times that of the open system in 2017, the open system exhibits more profit than photobioreactors [59]. When the lipid content reaches its peak concentration, the microalgae are harvested, which adds 20–30% to the cost of manufacturing. Centrifugation is a more expensive and energy-intensive way of extracting algae biomass. The flocculation process is thought to be effective since it uses less energy and has a lower initial investment of

Table 7
Combustion of different algae biodiesel blends in diesel engines.

Microalgae species	Engine Condition	Engine details	Blends	Combustion analysis compared to diesel fuel Net heat released rate(HRR)	Peak pressure	Reference
Fresh watrer algae	Varying power	Kirloskar, single-cylinder, four-stroke, diesel engine	Pure diesel	–	High peak pressure	[31]
Nanochloropsis sp.	Varying speed	Single cylinder, Ricardo E6 IDI, max power = 14.0 kW, CR = 22, injection timing – 20–45° BTDC	Diesel fuel, B100, B50, Raw algae oil	–	Maximum: B100 – 29.1 D – 25.9 @1440 rpm	[23]
Azolla pinnata	Varying power	Single cylinder, four-stroke, naturally aspirated, water-cooled, CRDI engine.	algae blends diesel fuel consumed minimum fuel	HRR visibly increases as the applied stress increases.	When compared to blended diesel, the peak pressure of diesel is only roughly 3 to 11% greater.	[56]
Crypthecodiniumcohnii	Varying power	Four cylinder, 2000CC, max power = 100 kW at 4000 rpm, CR = 18, turbocharged	Diesel fuel, B10, B20, B50	–	Maximum: B50 – 90.3 D – 96.7 at lower loads, at high loads no difference	[28]
neochlorisoleoabundans	Varying power	Kirloskar single cylinder, four-stroke diesel engine	B20 + 25 ppm, B20 + 50 ppm, B20 + 75 ppm, B20 + 100 ppm	The apparent net heat release increases rapidly and reaches the maximum value of the premixed fuel and air.	When compared to other fuel variations tested, the neat B20 blend has a somewhat lower peak pressure rise.	[32]
Chlorella protothecoides	Varying speed	Single cylinder, 2190 CC, rated power 3.09 kW @3600 rpm, fuel injection 16.5° BTDC.	Diesel fuel, B20, B50, B100		@ low rpm: B100 – 64.5 D – 69.5 @ high rpm: B100 – 56.8 D – 60	[3]
Gracelariaverrucossa	Varying power	four stroke, vertical, and air cooled Diesel engine	Diesel fuel B10 and B20	When compared to diesel, the heat release rate of biodiesel varies more. At 20° BTDC, the maximum heat release rates for Diesel, B10, and B20 are 53,131, and 129 kJ/m3 deg, respectively.	Biodiesel has a higher peak pressure than diesel. At 20°BTDC, the peak pressures of diesel, B10, and B20 are 51, 63, and 58 bar, respectively.	[30]

$2,000(Rs.1,64,755) /hm^{-2}. The filtration technology can be used to filter the pollutants with a cost of $9884(Rs.8,14,219) hm-2 and a higher efficiency. The favourable effects on the end cost of biofuel are demonstrated by the biomass productivity with higher lipid content [39]. With taxes included, it was anticipated that 10,000 tonnes of microalgae with 30% lipids would cost $2.80/L(Rs.230.65), which is more expensive than petroleum, which sells for $1.10/L(Rs.90.61). By implementing innovative technologies and preventing resource depletion, biofuels can be made more efficient. The efficient microalgae strain was discovered to reduce the cost of lipid synthesis because to its high lipid content and high biomass growth [46]. The cost of producing oil using the open pond and PBR cultivation methods is $8.52(Rs.701.85)/ gallon and $18.10(Rs.1,491)/ gallon, respectively, and the cost of converting the oil to biodiesel is $9.84(Rs.810.59) and $20.53 (Rs.1,691.21)/gallon of diesel. The lipid production in *Nannochloris* sp., *Dunaliella sp*., and *Chlorella* sp. was about 50% by weight. Co-cultivating several microalgae species lowers production costs while enhancing lipid yield. The cost to produce one gallon of biodiesel ranges from $9.8 (Rs.807.29) to 20.5(Rs.1,688.73), with prices starting at $5(Rs.411.88) to $22(Rs.1,812) per gallon. The reported biodiesel production levels ranged from 0.9 to 43 Gal-1. In contrast to PBRs, open pond cultivation of *Dunaliella salina* was economically feasible for the synthesis of carotene; however, the extraction of the pigment 18 astaxanthin makes the process profitable due to the greater market price of astaxanthin in PBR cultivation of *Haematococcus pluvialis.* The cost of producing carotenoids via biorefinery methods can be offset by achieving better recovery rates. The price of animal feed varies from $1384(Rs.1,14,010) to $5066 (Rs.4,17,324)/ MT [8 38].

9. Hindrances in practicability and commercialization

It has been suggested that investing a large sum of money is necessary to convert algae into biofuels because of their rapid growth rates, manageable growth densities, and high oil contents. However, there are a number of challenges to solve before algae can mature as an economically viable platform to replace petroleum and, as a result, decrease CO_2 release. These challenges range from how and where to cultivate these algae to enhancing oil extraction and fuel processing. The production chain for algae biofuels is depicted, and it is clear that strain separation, nutrient source and use, production management, harvesting, coproduct development, fuel extraction, refinement, and residual biomass usage are the main problems. Algal fuel commercialization is hampered by a number of factors, including the unreasonably high demand for a few essential resources, the high cost of manufacturing, and the requirement for energy ratios that are significantly higher than unity [25]. Researchers are looking into potential solutions to all of these issues, and it may be possible to produce specialty fuels like jet fuel on a limited scale in the future. Biodiesel are most definitely not expected to be widely accessible in the foreseeable future. Petroleum is being used more and more. It is impossible to replace a sizable portion of this usage with algal oil without the creation of new technology. It is vital to do focused study on both the biology of algae and the engineering of production systems. In addition, supporting technologies including those that increase atmospheric carbon dioxide concentration [62].

In the present situation, the cost of the microalgae biodiesel was estimated to be $20.53 and $ 9.84 per gallon when cultivating the microalgae biomass using open raceway pond and photobioreactor. Though many microalgae species are there for biodiesel production only few microalgae species are considered to be a best choice due to its quality and quantity of lipid accumulation capabilities. Presently, though number of microalgae species are available for biodiesel production still lot of limitations and challenges in its accumulation and its conversion are faced. These issues can be addressed by either improving the technologies right from the laboratories to the commercial scale. The dewatering of cultivated microalgae and biomass productivity; pretreatment of microalgae, extraction of lipid and biodiesel production. Though lot of technologies are available for these large scale production and conversion still, microalgae cultivation system requires temperature and growth limiting condition control is required. The dewatering of microalgae is the most crucial obstacle due to its energy intensive and costly. The major challenge faced is during the lipid extraction which is very expensive solvents are used which increases the production cost. For the biodiesel production, a neat lipid is required with less FFA content to bypass the esterification process using acid which parallelly reduces the production cost.

10. Future perspectives

Microalgae are a broad group of single-celled organisms that may provide a range of options for meeting our needs for liquid transportation fuel in a number of ways. Algal species can flourish in a variety of freshwater and saltwater aquatic environments. More over 40% of the world's carbon is fixed by algae, with marine microalgae producing the majority of its productivity. Algae are excellent CO_2 oxidizers. Algae can grow biomass very quickly; many species show two doublings per day, and other species can double in as little as 6 h. All algae have the ability to create energising oils, and certain microalgal species have been discovered to naturally accumulate high oil levels in overall dry biomass. Microalgae are superior than terrestrial plants in several ways. High-throughput technologies can be utilised to quickly evolve strains since they are single-celled organisms that reproduce through division. This can speed up processes in algae that might otherwise take years in agricultural plants. Compared to terrestrial forms of biomass used for biofuels, algae have less of an impact on the environment. They are particularly effective in removing nutrients from water and can be cultivated on area that would not be suitable for typical agriculture. Thus, compared to the production of biofuels from terrestrial plants, the production of algae-based fuels would consume less land and allow for the remediation of waste streams.

The current cost of per litre of microalgae-based biodiesel is about $ 50 which makes algal biofuel unsuccessful at commercial scale. Research work is still in progress in order to reduce the cost and to make the algal biofuel production at commercial success. The most promising way for the successful biodiesel production is to reduce the nutrient cost and the cultivation cost. One best way reduce the cultivation cost of microalgae would be the use of wastewater from industrial, municipal and agricultural for the large scale- cultivation. The low-cost biomass production can be achieved by the use of wastewater effluents from different sectors can be recommended. Currently, the price of the crude oil is less, therefore the biodiesel production from microalgae should be economically uncompetitive when compared with conventional diesel. If the following problems such as use of high efficiency and low-cost biomass production system, cultivation mode, utilization of wastewater and flue gas for algal cultivation, novel microalgal harvesting technologies, low-cost extraction techniques and transesterification methods are addressed by the researcher the microalgae-based biodiesel can be commercialized easily.

11. Conclusion

Algae are an efficient and useful biofuel feedstock that can be used as a better alternative energy source. The present article discussed all of the benefits and drawbacks of algae as a biodiesel source. Traditional biodiesel sources have numerous drawbacks, including higher land requirements, nutrient supply, and oil yield. Algae may be a better option for overcoming these primary challenges. However, growing algae under controlled temperature conditions necessitates a significant amount of water. Technically, algae biodiesel research is still subpar due to poor filtration techniques and high costs. According to the findings of the recent study, algae biodiesel has the potential to compete with other major biodiesel sources. The factors that influence engine performance are all same for algae biodiesel as well as other conventional biodiesel fuels. Other than the cold flow properties, the other major fuel properties are well within acceptable limits. As needed, minor engine modifications and additive blended algae fuels may be effective. Now a days, microalgae biodiesel act as an alternative resource for various industrial and environmental applications. So far, we could able to see that the micro-algal biodiesel production is stuck due to it cost factor only. It is clearly seen that zero nutrient cost technology for algal cultivation, cost effective large scale harvesting technologies and the conversion of lipid to biodiesel are need to be improved. The microalgae-based biodiesel production at commercial scale plays a vital role in the present scenario and concerns towards the related environmental issues. Microalgae being a third-generation biofuel will be satiating the energy demand and its challenges in the future are believed by the researchers. Therefore, the establishment innovative technologies would help to bring down the cost of algal biodiesel production.

CRediT authorship contribution statement

Anish Mariadhas: Conceptualization. **B. Sathish Kumar:** Writing – original draft. **K. Kabilan:** Writing – original draft. **Jayaprabakar Jayaraman:** Conceptualization. **Karthikeyan Alagu:** Conceptualization. **Nivin Joy:** Conceptualization. **J. Arun:** Conceptualization, Writing – review & editing. **S.S. Dawn:** Conceptualization, Writing – review & editing. **N. Nirmala:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

The authors would like to express their sincere thanks to freepik.com and Centre for Waste Management, Centre of Excellence for Energy Research, Sathyabama Institute of Science and Technology, Chennai, India for their continuous support rendered to pursue the research. The authors wish to thank the Department of Science and Technology, Government of India (Grant No: DST/SEED/SCSP/STI/2021/495) for financial support to pursue this activity.

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