A Critical Review of Biofuels From Algae for Sustainable Development

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ABSTRACT
Algae is a very promising source of biomass in this context as it sequester a significant quantity of carbon from atmosphere and industrial gases and is also very efficient in utilizing the nutrients from industrial effluents and municipal wastewater. Therefore cultivation of algal biomass provide dual benefit, it provides biomass for the production of biofuels and also save our environment from air and water pollution.
Algae are the fastest-growing plants in the world. Industrial reactors for algal culture are open ponds, photobioreactors and closed systems. Algae are very important as a biomass source. Algae will some day be competitive as a source for biofuel. Algae are among the fastest-growing plants in the world, and about 50% of dry algae weight is oil. This liquid oil can be used to make biodiesel for cars, trucks, and airplanes. Algae have much faster growth-rates than terrestrial crops. the per unit area yield of oil from algae is estimated to be from 20,000 to 80,000 l per acre, per year; this is 7–31 times greater than the next best crop, palm oil.
The experimental investigation was conducted on a single cylinder, four stroke, vertical, air-cooled diesel engine. It is concluded from the experiment that the brake thermal efficiency with algae biodiesel was found lower than that of diesel fuel at all load conditions. There is a significant reduction in the emission of CO, HC and Smoke intensity, which make this biodiesel as environmental friendly. On the other hand, NOx emission is higher for this biodiesel compared to neat diesel operation.

Keywords
Biodiesel, Algae, Biofuels and Transesterification

1. INTRODUCTION
Due to depleting reserves and rising prices of fossil fuels, interest has rightly begun in the development of renewable energy sources. In year 2010, fossil fuels accounted for 88% of the global primary energy consumption [1]. The current technological progress, potential reserves, and increased exploitation leads to energy insecurity and climate change by increasing greenhouse gas (GHGs) emissions due to consumption of energy at a higher rate. The use of fossil fuels is now widely accepted as unsustainable due to depleting resources and the accumulation of GHGs in the environment that have already exceeded the ‘‘dangerously high” threshold of 450 ppm CO_2 [8]..
Biodiesel has become a sustainable substitute to diesel fuel as biodiesel is produced from vegetable oil or animal fat through a chemical process known as transesterification. The research on different aspect of biodiesel production and utilization in diesel engine has been reported by a number of researchers [2]. Algae have much faster growth-rates than terrestrial crops. the per unit area yield of oil from algae is estimated to be from 20,000 to 80,000 l per acre, per year; this is 7–31 times greater than the next best crop, palm oil [2]. Biodiesel from algae seems to be only renewable biofuel that has the potential to completely displace petroleum-derived transport fuels without adversely affecting supply of food and other crop products. The table 1 shows the comparison of production of different oils per hector.

Table 1: Comparison of Production of Different Oils per Hector [2]

Source	Oil Yield (l/ha)
Cotton	325
Soyabean	446
Mustard Seed	572
Sunflower	952
Oil Palm	1,892
Jatropha	5,950
Canola	1,190
Algae	**98,500**

2. BIODIESEL
Biodiesel is an esterified version of vegetable oil, which could be edible or non edible. B20 (a blend of 20 % by volume biodiesel and 80 % by volume diesel) has demonstrated significant environmental benefits in the U.S. within a minimum increase in the cost for fleet operation and other consumers. Biodisel is registered as a fuel and fuel additive with the U. S. Environmental Protection Agency, and it meets clean diesel standards established by the Califorina Air Resources Board. Neat (100%) biodiesel has been designated as an alternative fuel by the U.S. Department of Energy and the Department of Transportation. Studies conducted with biodiesel on engines have shown substantial reduction in PM (25% - 50%). However, a marginal increase in NOx (1%-6%) is also reported; but it can be taken care of either by optimization of engine parts or by using De-NOx catalyst. HC and CO emission were also reported to be lower. No-regulated emissions like poly aromatic hydrocarbons were also found to be lower. [10]

3. FIRST AND SECOND-GENERATION BIOFUELS
First-generation biofuels which have attained economic levels of commercial production, have been mainly extracted from food and oil crops (viz. rapeseed oil, palm oil, sugarcane, sugar beet, wheat, barley, maize, etc.) as well as animal fats using conventional technology.
Second-generation biofuel crops and production technologies are more efficient; their production could become unsustainable if they compete with food crops for available land. Thus, their sustainability will depend on whether producers comply with criteria like minimum lifecycle GHG reductions, including land use change, and social standards [8]. The limitations of first-generation biofuels produced from food crops have caused greater emphasis to be placed on second generation biofuels

produced from lignocellulosic feedstocks, although significant progress continues to be made to overcome the technical and economic challenges, second-generation biofuels production will continue to face major constraints to execute commercial deployment [1].

4. THIRD GENERATION BIOFUELS FROM ALGAE

Several biofuel candidates were proposed to displace fossil fuels in order to eliminate the vulnerability of energy sector. Biodiesel and bioethanol produced from terrestrial plants have attracted the attention of the world as potential substitute. However, due to food vs. fuel competition as well as land consumption of these biofuels, they have brought much controversy and debate on their sustainability [6]. In this respect, cultivation of macroalgae at sea water or industrial or other waste water provides a possible solution for this energy issue. Microalgae are single-cell, photosynthetic organisms known for their rapid growth and high energy content. Some algal strains are capable of doubling their mass several times per day. In some cases, more than half of that mass consists of lipids or triacylglycerides. [1] Not all algal oils are satisfactory for making biodiesel, but suitable oils occur commonly. The growth medium must provide the inorganic elements that constitute the algal cell. Essential elements include nitrogen, phosphorus, iron and in some cases silicon [6].

Third generation technology is based on algae or cyanobacteria that contain a high oil mass fraction grown in ponds. Micro-organisms can convert almost all of the energy in biomass residuals and wastes to methane and hydrogen. Under proper conditions, these micro-organisms can produce lipids for biodiesel with yields per unit area that are many fold higher than those with any plant system [1] in a study reported, an increase in the biomass production and lipid accumulation with a CO_2 concentration increase in the aeration. However, it is still not proven that this high efficiency can be maintained after scaling-up the technology to a large production plant. Biodiesel production from algae is the promising technology [6] studied the impacts associated with algae production using a stochastic life cycle model and compared with switchgrass, canola and corn. The results of Clarens's study indicate that these conventional crops have lower environmental impacts than algae in energy use, greenhouse gas emissions, and water regardless of cultivation location. Only in total land use and eutrophication potential do algae perform favorably.

5. ALGAE CULTIVATION SYSTEM

There are different methods used for the cultivation of algae the following are the three commonly used methods.

- Open Pond System
- Closed System
- Photobioreactor

5.1 Open Pond System

Open pond system is a simple system in which shallow ponds are used to cultivate algae. Nutrients can be provided through runoff water from nearby land areas or by channeling the water from sewage or from water treatment plants. Some source of waste carbon dioxide could be efficiently bubbled into the ponds and captured by the algae for its faster growth. [4]

Fig. 1: Open Pond System

5.2 Closed System

A variation on the basic "open-pond" system is to close it off, to cover a pond or pool with a greenhouse. While this usually results in a smaller system, it does take care of many of the problems associated with an open pond system Closed systems are much more expensive than ponds. However, the closed systems require much less light and agricultural land to grow the algae. High oil species of microalgae cultured in growth optimized conditions of photobioreactors have the potential to yield 19,000–57,000 liters of microalgal oil per acre per year.[4]

5.3 Photobioreactor (PBR)

Algae can also be grown in a photo-bioreactor (PBR) as shown in figure 2. A PBR is a close bioreactor which incorporates some type of light source. A variation on the basic open-pond system is to enclose it with a transparent or translucent barrier. Like this, a pond covered with a greenhouse could be considered as a PBR. Because PBR systems are closed, all essential nutrients must be introduced into the system to allow algae to grow and be cultivated. It is possible to introduce a continuous stream of sterilized water containing nutrients, air and carbon dioxide. As algae grows, excess culture overflows and is harvested.[7]

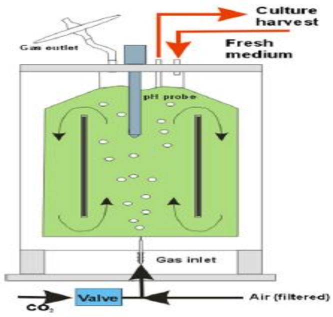

Fig. 2: Photobioreactor (PBR)

6. ALGAE HARVESTING

Harvesting is a very important process for efficient biodiesel production from algae because algae biomass content lots of solid particles and slurry which are not of any use and there is need to remove it. For removing solid particles, different processes are used such as flocculation, flotation and gravity sedimentation. For removing slurry filtration and centrifugation method are used.[4]

7. OIL EXTRACTION FROM ALGAE

Harvested algae is dried (from 10 kg of wait algae we get 1 kg of dry algae). Dry algae retain its oil content, which then can be "pressed" out with an oil press. Using Expeller press as shown in figure 3 oil is extracted from dry algae (0.5 kg of oil is obtained from 1 kg of dry algae). Since different strains of algae vary widely in their physical attributes, various press configurations (screw, expeller, piston, etc) work better for specific algae types [5]

Fig. 3: Expeller press

8. PRODUCTION OF BIODIESEL FROM ALGAE OIL

Biodiesel is defined as the mono-alkyl esters of vegetable oils or animal fats. Biodiesel is produced by transesterifying the parent oil or fat to achieve a viscosity close to that of petrodiesel. The chemical conversion of the oil to its corresponding fatty ester (biodiesel) is called transesterification. Biodiesel is a biofuel commonly consisting of methyl esters that are derived from organic oils, plant or animal, through the process of transesterification. The biodiesel transesterification reaction is very simple [2]

Triglyceride + 3 methanol $\xrightarrow{\text{Catalyst}}$ Glycerine + 3 methyl esters (Biodiesel)

An excess of methanol is used to force the reaction to favor the right side of the above equation. The excess methanol is later recovered and reused. The energy density of biodiesel is comparable to petroleum diesel. The higher heating value of petroleum diesel is 42.7 MJ/kg. Values for biodiesel vary depending on the source of biomass. Typically, biodiesel derived from seed oils, such as rapeseed or soybean produces, 39.6 MJ/kg, while biomass derived from algae yields 39.5 MJ/kg [2]. Although the lower energy biodiesels based on seed oils are the most common, they have enough energy density to make them a viable alternative to petroleum diesel. The lower heating value of algae biodiesel is compared with the other biodiesel and diesel in table 2.

Table 2: Comparison of Calorific Value of Diesel with Different Biodiesel [2]

Oil	Lower Heating Value (MJ/kg)
Diesel	42.7
Jatropha	39.7
Sunflower Oil	39.6
Soya bean	39.6
Karnja	38.8
Algae	39.5

8. Experimental Investigation of Algae Biodiesel as an alternative fuel for diesel engine

The experimental investigation has been carried out by the researcher on a single cylinder, four strokes, vertical, air-cooled diesel engine. The compression ratio is 17.5. It develops 7.4 kW brake power at rated speed of 1500 rpm with algae biodiesel as fuel. [9] The test were carried out at steady state with different loads of 0%, 20%, 40%, 60%, 80% and 100% at the engine maximum torque speed of 1500 rpm. The engine was initially run on diesel fuel to generate base line data and after that it was run on algae biodiesel. Similar loading conditions were used for both the fuels. The smoke opacity was measured with an AVL 437 smoke meter and exhaust emission were by AVL 4000 light 5 gas analyzer. The original mechanical inline fuel injection system was used for injecting diesel or biodiesel, and the fuel injection timing was not adjusted throughout the test. At each engine mode, the engine was allowed to run for a few minutes the exhaust gas temperature, the lubricating oil temperature and the gaseous emission concentration reached steady state values and data was measured subsequently. [9]

9. RESULT AND DISCUSSION

A graph of brake thermal efficiency (BTE) vs. brake mean effective pressure (BMEP) is shown in figure 4. From the test results of algae biodiesel, it was observed that brake thermal efficiency of mineral diesel is higher than algae biodiesel (AB). It was also observed that the power produced by algae biodiesel is lower than that by mineral diesel. This may be due to the lower calorific value of algae biodiesel and its higher density and kinematic viscosity. The lower brake thermal efficiency obtained for AB100 fuel could be due to the reduction in calorific value and increase in fuel consumption as compared to diesel fuel. This indicates that the thermal efficiency is a better representative reflection of the fuel economy by using the diesel equivalent energy consumption rate when operated on oxygenated fuels like algae biodiesel.[9]

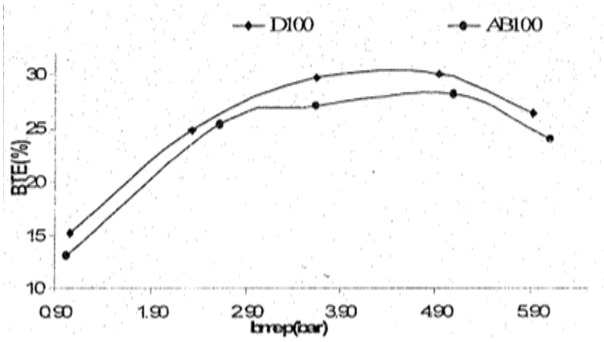

Fig 4: Brake Thermal Efficiency (BTE) Vs. Brake Mean Effective Pressure (BMEP)

10. CO EMISSION

Figure 5 depicts the CO emission versus brake mean effective pressure for different biodiesel fuels. CO emissions were found to be lower for algae biodiesel. As the load is increased on the engine, there is an increase in CO emission for both fuels. The increase in CO emission levels at higher load is due to richer load condition than at lower level which results in incomplete combustion of fuels. Within the experimental range, the lower CO emissions have been observed with AB100 sample. This is possible since biodiesel contains more oxygen than diesel most of the carbon monoxide is converted into carbon dioxide and hence complete combustion takes place. The maximum value of carbon monoxide present in Algae Biodiesel (AB100) is 0.4% and corresponding value of CO present in diesel is 0.61% which is significantly higher than that in algae biodiesel.[9]

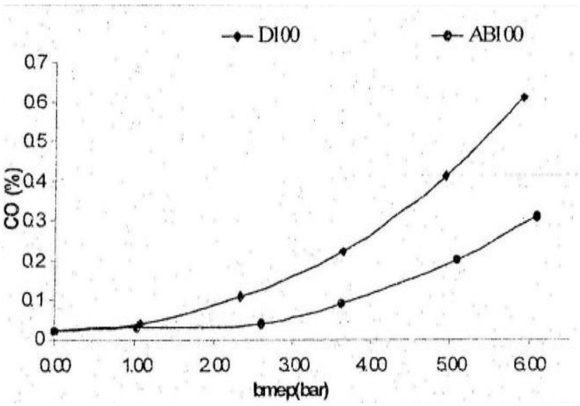

Fig. 5: CO Emission Vs Brake Mean Effective Pressure

11. UBHC EMISSIONS

Figure 6 shows the variation in unburned Hydrocarbon Emission vs. brake mean effective pressure for algae biodiesel and diesel. The unburned hydrocarbon emissions are found lower at partial load conditions and increases at higher engine load. This is due to relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at higher engine load. Hydrocarbon emissions are mainly caused due to the incomplete combustion of hydrocarbon fuel. The maximum reduction in UBHC was achieved for algae biodiesel.[9]

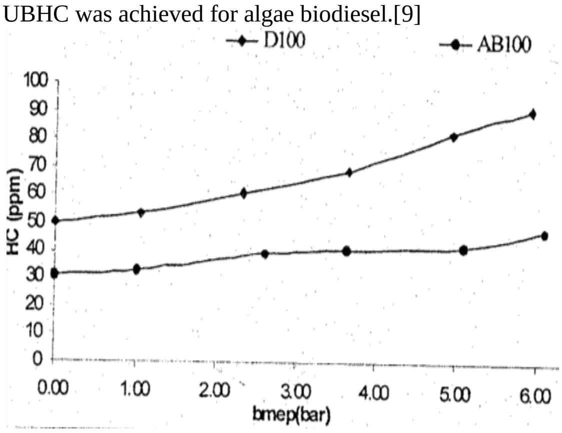

Fig. 6: Unburned Hydrocarbon Emission Vs. Brake Mean Effective Pressure

12. NOX EMISSIONS

NOx emissions from diesel engine fueled with algae biodiesel and diesel at different load conditions are shown in figure 7. The principal source of NOx formation is the oxidation of atmospheric nitrogen at sufficiently high temperatures. The NOx emissions are determined by equivalence ratio, oxygen concentration, combustion temperature and time.

NOx are formed in cylinder areas where high temperature peaks appear during the uncontrolled combustion. The NOx emissions of algae biodiesel has been found higher than diesel at higher loads. The NOx emission for algae biodiesel fuels is much higher than the diesel from no load to full load conditions. The maximum value of NOx emissions for AB100 at full load is 3129ppm..[9]

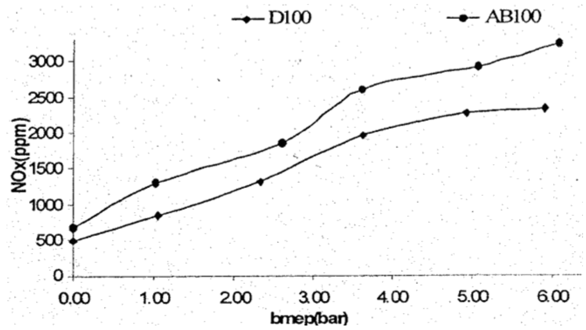

Figure 7: NOx emissions Vs. Brake Mean Effective Pressure.

13. SMOKE OPACITY

Figure 8 indicates smoke opacity versus brake mean effective pressure for diesel and algae biodiesel. It can be seen that smoke opacity is high mainly at high power outputs. High loads imply that more fuel is injected into the combustion chamber and hence incomplete combustion of fuel is prominent. Reduction of smoke emission for algae biodiesel in comparison to diesel fuel has been achieved for all load conditions. This factor leads to the improvement of combustion quality for algae biodiesel when compared with diesel fuels.[9]

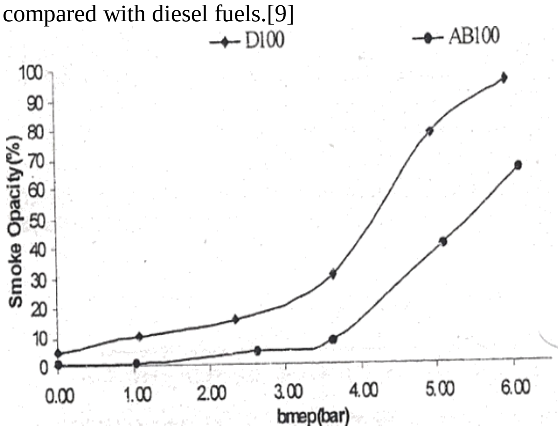

Fig. 8: Smoke Opacity Vs Brake Mean Effective Pressure

14. CONCLUSIONS

This work investigated the production of biodiesel from microalgae and performance study of diesel engine with diesel fuel and algae biodiesel. The results of this report are summarized as follows:

- The yield of algae per acre is very high as compared to any other bio diesel.
- Calorific value of algae biodiesel is 39.5 MJ/kg which is near to the calorific value of diesel.
- Algae were produced by algae photobioreactor and the transesterification process was carried out to produce algae biodiesel.
- The brake thermal efficiency of algae biodiesel was lower than diesel fuel due to lower calorific value, higher density and kinematic viscosity.
- Algae biodiesel showed the reduction in emission of CO, HC and Smoke Opacity as compared to diesel whereas NOx have been found to be higher for algae biodiesel.
- As the ignition delay is lower for algae biodiesel, the net heat release rate for algae biodiesel is found to be lower as compared to diesel.

5. REFERENCES

[1] Anoop Singh, Poonam Singh Nigam, Jerry D. Murphy "Renewable fuels from algae: An answer to debatable land based fuels" Bioresource Technology 102 (2011) 10–16

[2] Ayhan Demirbas, M. Fatih Demirbas, "Importance of algae oil as a source of biodiesel" Energy Conversion and Management 52 (2011) 163–170

[3] Brennan, L., Owende, P., 2010. Biofuels from microalgae-a review of technologies for production, processing, and extractions of biofuels and co-products. Renew. Sustain. Energy Rev. 14, 557–577.

[4] Chun-Yen Chen, Kuei-Ling Yeh, Rifka Aisyah, Duu-Jong Lee, Jo-Shu Chang, "Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: A critical review" Bioresource Technology 102 (2011) 71–81

[5] David Sieg "Making Algae Biodiesel at home"

[6] Goh, C.S., Lee, K.T., 2010. A visionary and conceptual macroalgae-based thirdgeneration bioethanol (TGB) biorefinery in Sabah, Malaysia as an underlay for renewable and sustainable development. Renew. Sustain.Energy Rev. 14, 842–848

[7] J. Pruvost, G. Van Vooren, B. Le Gouic, A. Couzinet-Mossion, J. Legrand "Systematic investigation of biomass and lipid productivity by microalgae in photobioreactors for biodiesel application" Bioresource Technology 102 (2011) 150–158

[8] Schenk, P.M., Thomas-Hall, S.R., Stephens, E., Marx, U.C., Mussgnug, J.H., Posten, C., Kruse, O., Hankamer, B., 2008. Second generation biofuels: high-efficiency microalgae for biodiesel production. Bioenergy Res. 1, 20–43

[9] Sharma P. B., et. Al. "Biodiesel Production from Microalgae A Sustainable Fuel" New Frontiers in Bio Fuels, Scitech Publications (India) PVT. LTD., New Delhi.

[10] S.S. Tipse., "Alternative fuels" Jaico Book publisher.