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Production of Biodiesel from Microalgae Using Heat Extraction Method and Its Performance and Emission Testing In Crdi Engine

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Abstract: *With the growing need of fuels for various activities like transportation and power generation the need for fuel has increased. Keeping this objective in mind we decided to pursue our project on production of biodiesel from algae. The reason we chose this as our project is because of ability to cultivate algae on large scale. After testing with other species of algae we chose Sargassum as it gave us 20-30% oil on 1 kg of algae.*
After the selection of the species we went to the Talpona beach in goa to search for the algae. We managed to collect 50kg of wet algae. After collecting the algae we dried the algae in the presence of sunlight. This was done to remove the water present in the algae. Once the drying processes was completed we moved to the grinding of the dried algae using a grinder. The powdered algae was boiled to obtain the oil. The oil that was obtained was used to generate biodiesel using the transesterification process in a biodiesel plant. We ran the biodiesel obtained in a CRDI engine and the emission characteristics were found.
The high calorific value of this biodiesel indicates that high power would be generated in the engine. This would help to run the engine with less fuel. It was found that only NOx emission for combustion of this biodiesel is higher than that of diesel, whereas emission of other gases like CO, CO2 along with unburned hydrocarbon, can be reduced many fold if this biodiesel is used instead of petro-diesel.
Keywords: *Algae, biofuel, fossil fuel, transesterification, oil, glycerine.*

I. Introduction

Bioenergy is one of the most prime element to mitigate greenhouse gas emissions and substitute of fossil fuels. The need of energy is increasing unceasingly, because of increase in industrialization and population. The fundamental sources of this energy are petroleum, natural gas, and coal, hydro and nuclear. The major drawback of using petroleum based fuels is atmospheric pollution generated by the use of petroleum based fuels. Petroleum diesel combustion is a major source of greenhouse gas. Apart from these emissions, petroleum diesel is also major source of other air contaminants including NOx, SOx, CO, particulate matter and volatile organic compounds.

So to lessen the use of fossil fuels we have come about with an alternative fuel using algae. The algae species used in this biodiesel blend is Sargassum, which is seasonal and found on the beaches of Goa. The type of algae used is found only during winter and only at rocky beaches. The best part about this algae is none of its parts get wasted. As engineers we are trying to save the environment, reduce the use of fossil fuels and trying to find as many fuel alternatives as possible.

The burning of a vast amount of fossil fuel has increase CO2 level in the atmosphere, causing global warming. Biomass has been focused on as an alternative energy source, since it is a renewable resource and it fixes COx in the atmosphere through photosynthesis. If biomass is grown in a sustained way its combustion has no influence the CO2 balance in the atmosphere, because the CO2 emitted by the burning of biomass is offset by the CO2 fixed by photosynthetic. Among biomass, algae (macro and microalgae) usually have a higher photosynthetic efficiency that other biomass.

Shay reported that algae were one of the best sources of biodiesel. In fact algae are the highest yielding feedstock for biodiesel. It can produce up to 250 times the amount of oil per acre as soybeans. In fact, producing biodiesel from alga may be only the way to produce enough automotive fuel to restore current gasoline usage. Algae produce 7 to 31 time greater oil that palm oil. It is very simple to extract oil from algae. The bestalgae for biodiesel would be microalgae. Microalgae are an organism capable of photosynthesis that is less than 2 mm in diameter. Macro algae, like seaweed, are not as widely used in the production of biodiesel. Microalgae have much more oil than macro algae and it is much faster and easier to grow.

Microalgae can provide several different types of renewable biofuels. These incorporate methane produced by anaerobic digestion of the algal biomass biodiesel derived from micro algal oil and photo biologically produced bio hydrogen. The idea of using microalgae as a source of fuel is not new but it is now being taken seriously because of the escalating price of petroleum and more significantly, the emerging concern about global warming that is associated with burning fossil fuels.

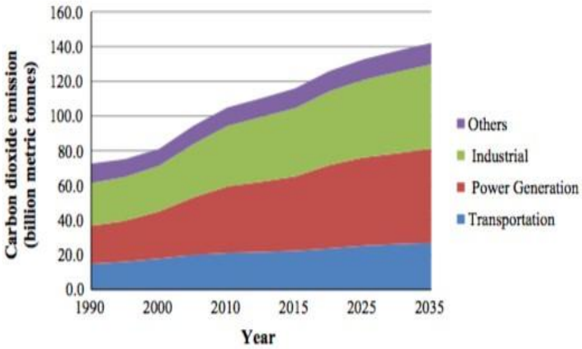

Fig 1.1 Global co_2 emission from various sectors from 1990 to 2035[1]

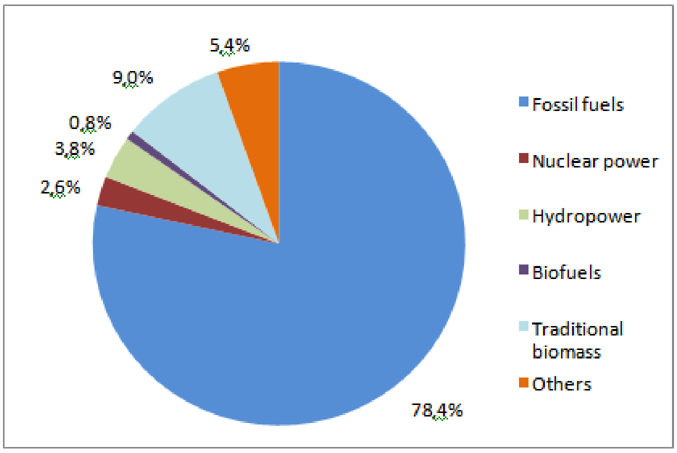

Fig 1.2 World primary energy consumption in the year 2014[2]

II. Methods and Methodology

Microalgae are photosynthetic aquatic organisms. They are made up of eukaryotic cells. The algae were collected from different beaches in Goa in the winter season. Eutrophication and algal blooms take place in these water bodies during these times of immobilization of the nutrient these algae degrade naturally with time or flow away from the current of the water increases. Most of the time these algae are treated as wastes and remain unused.

3.1 Microalgae strain selection

Microalgae are small unicellular organisms which can be either prokaryotic or eukaryotic that can carry out photosynthetic process and are amongst the oldest living micro-organisms. Microalgae being a simple organism it requires basic nutrients i.e., they capture solar energy and photosynthesis to split water and fix carbon dioxide. Microalgae are an enormously diverse group of primary producers, abundant in almost all ecosystems on earth ranging from marine and freshwater environments to desert sands, from hot springs to snow and ice. Microalgae are considered to have great potential due to; their ability to grow on marginal lands. their ability to grow in wastewater, often thereby effecting wastewater treatment as well, they have fast growth rate as compared to other land plants and their capability to sequester flue gas emissions under appropriate conditions.

There are more than 200,000–800,000 algae species, of which around 50,000 species have been described. Compared to macroplants, the main advantage of microalgae is the much lower land area demand, the easy to cultivate them, and the fact that wastewater can be used as algal nutrient (N, P and K) [3]

3.2 Cleaning

The algae was collected from the sea, so it needs to be cleaned of any impurities like sand, dust particles etc. The algae has to be rinsed in water at least three to four times to get rid of the impurities. Once this process is done the algae has to be weighed and we collected around 40kg of wet algae.

3.3 Drying of algae

After rinsing it in fresh water, the algae was left do dry in the sun for a day. For the next 3-4 days we used paper and weights to remove any of the wet content in it .For the final day of drying it was put under the hot sun to make sure that all the moisture content was removed.

3.4 Grinding

For this process the leaves and the seeds had to be separated, the dry algae was converted into powder. The weight of the algae after this process was around 5kgs.

3.5 Heat extraction method (Raw test)

This process is done in batches where 50gms of algae is mixed with water. This mixture of algae and water is heated for about 30 mins and then cooled till the fat, water and algae for three separate layers. The algae is separated from the mixture with the help of a strainer. The fat and water mixture is again heated for 10 mins so that the layers of water and oil are clearly separated and left untouched for two days. When all the particles settle down it forms three layers, the bottom layer is of the fine algal particles, the middle layer is water and glucose and the top layer is algal fats.

3.6 Transesterification

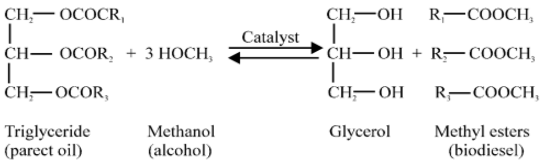

Fig 3.1 Line diagram of a biodiesel plant

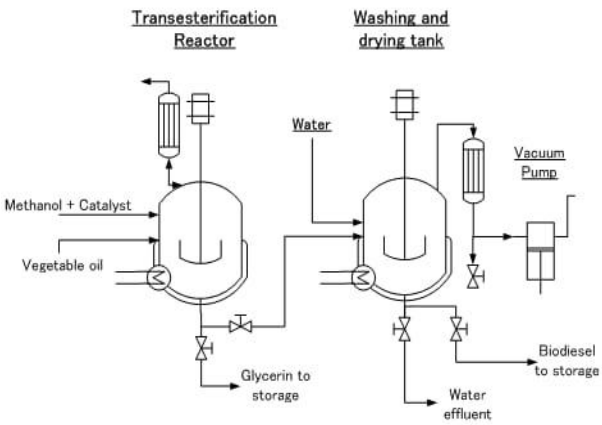

Fig 3.2Biodiesel plant

In making biodiesel, the algal oil is reacted with the methanol to produce glycerol plus biodiesel.

3.7 Performance and emission testing

1) The performance characteristics of the engine is evaluated in terms of brake thermal efficiency.
2) Then the brake specific fuel consumption, and emission characteristics in terms of smoke is calculated.
3) The use of biodiesel leads to substantial reduction in PM, HC and CO emissions accompanying with the imperceptible power loss.

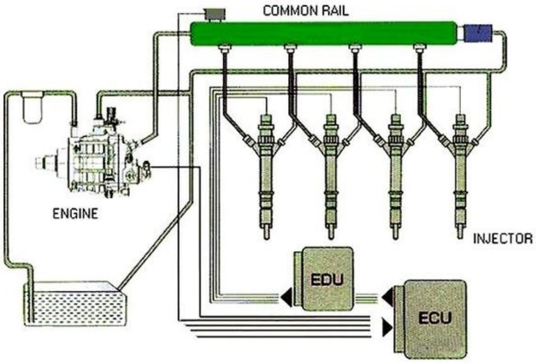

Fig 3.3 CRDI engine

3.8 Acid Number

The titration method was used to estimate the acid number of the biodiesel. A 0.1–0.5 mL of biodiesel was taken in a conical flask. A 50 mL of solvent mixture (95% ethanol and diethyl ether in 1:1 ratio) was added to it and mixed thoroughly. This solvent–oil mixture was titrated with0.1 M KOH using 1% phenolphthalein indicator.[4]

3.9 Calorific Value

A bomb calorimeter (Widsons) was used to measure the calorific value of the algal biodiesel. The biodiesel (0.5 g) in a container was placed in the bomb, and a 8-cm cotton thread hanging from an 8-cm nichrome wire was dipped into the biodiesel. The bomb was filled with oxygen at 400 psi. Then, it was placed inside the insulated container containing distilled water and the fuse wires were placed in their position on the bomb. The nichrome wire was stuck to two sticks attached to the fuse wires. The initial temperature was noted, and then it was reduced to zero (0 _C). The fire button was pressed to make a short circuit on the nichrome wire and ignite the biodiesel. The temperature kept on increasing for a certain time. The temperature was noted when it was stable.[5]

3.10 Flash and Fire Point

The biodiesel was kept inside the flash and fire point apparatus, and a cotton thread was placed in it. The biodiesel was heated with a gas stove. Another ignited cotton thread was dragged on the surface of the former thread. The temperature at which the spark came out of first thread was noted as the flash point of the biodiesel, and the temperature at which the thread started burning was noted as the fire point of the biodiesel.[6]

3.11 Carbon Content

The biodiesel (5 g) was put inside a pre-weighed heat proof glass bulb and placed inside the carbon residue content apparatus (preheated at 450 _C) and kept there for half an hour. The weight of the bulb was measured after its temperature dropped to room temperature.[7]

3.12 Cloud and Pour Point

The cloud and pour point apparatus was filled up with ice. The glass vessels of this apparatus, filled up with biodiesel, were placed in their slots of the apparatus. The temperature at which the paraffin in the biodiesel started solidifying and cloudiness appeared in the biodiesel was noted as the cloud point. The temperature at which the biodiesel becomes semi-solid was noted as the pour point of the algal biodiesel.[8]

3.13 Ash Content

The sample (5 g) was taken in a pre-weighed quartz crucible and placed inside a muffle furnace (preheated at 450 _C). After half an hour, when the biodiesel burnt completely to ash, the crucible was taken out. The crucible was weighed again when its temperature dropped to room temperature.[9]

3.14 Emission Characteristics of Biodiesel

The produced algal biodiesel (B100) and petro-diesel were used to run a CI engine. A di-gas analyser (AVL 444) was used to check the emissions in the exhaust of the engine. The probe of the analyser was placed inside the exhaust, and the quantity of CO, CO2, NOx, unburned hydro carbon (HC) was measured along with the exhaust temperature (measured with a thermometer) at different engine loads (0%, 20%, 40%, 60%, 80%, 100%, 110%).[10]

4.1 Advantages

1) Availability and renewability of biodiesel.
2) Higher combustion efficiency of biodiesel.
3) Lower emissions by using biodiesel.
4) Biodegradability of biodiesel.
5) It uses large volumes of carbon dioxide.
6) Its basic source can reproduce fast.
7) It has the potential to produce high energy content.

4.2 Applications

1) It is a great alternative for petroleum and diesel.
2) Algal production systems can contribute to rural development through diversification to integrated systems by efficiently coproducing energy together with valuable nutrients, animal feed, fertilizers, biofuel and other products.
3) Products can be customized on the basis of the local needs.

V. Result and discussion

5.1 Biodiesel properties

All the properties of the algal biodiesel were within the ASTM standard limits. The acid number of the algal biodiesel (0.697 mg KOH/g) was a little higher than that of petro-diesel (0.35) (Singh and Padhi 2009), but it does not harm the engine parts. The calorific value (CV) of any fuel plays an important role as higher calorific value indicates higher power generation to run an engine. Although the calorific value of the biodiesel produced in this experiment was lower (40,666 kJ/kg) than that of petrol or diesel, it was higher than the CVs of coal or popular biodiesels like palm and Jatropha . Both viscosity and density of the algal biodiesel (3.30 mm2/s and 880 kg/m3, respectively) were almost equal to those of petro-diesel (1.9–4.1 mm2/s (Knothe and Steidley 2005) and 832 kg/m3, respectively) which indicates good atomization and complete combustion of the biodiesel inside the engine and a healthier engine life. The flash and fire points of the biodiesel were much higher (152 and 154 C, respectively) , and thus better, than those of petro-diesel (flash point 93 C and fire point 102 C) because higher flash and fire points reduce the chance of unexpected fire hazard. On contrary, the cloud and pour points of the produced fuel were higher (1.02 and -2.69 C, respectively) than those of diesel, though these were less than those of other biodiesels. So for these cold flow properties, algal biodiesel produced in this procedure can be used in cold atmospheric conditions. Biodiesel additives may be required if the temperature of the atmosphere is below 0 C. Lower ash content and carbon residue content produce lower deposition of carbon on engine parts and increases the engine life. The ash content of the algal biodiesel produced here was 0.013% , and the carbon residue content was 0.044% . So both the last two properties of the algal biodiesel were also low enough that the biodiesel can be used in an unmodified CI engine.[11]

No.	Fuel property	Algal biodiesel	ASTM standards
1	Acid number, mg KOH/g	0.50	0.50 (maximum)
2	Calorific value, kJ/kg	40,666	–
3	Kinematic viscosity at 40 °C, mm^2/s	3.16	1.9–6
4	Relative density at 15 °C, kg/m^3	880.5	860–900
5	Flash point, °C	150	93 (minimum)
6	Fire point, °C	153	–
7	Cloud point, °C	1	3 (maximum)
8	Pour point, °C	−2.7	–
9	Ash content, %	0.01	0.01 (maximum)
10	Carbon residue, %	0.037	0.50 (maximum)

Fig 5.1 Properties of algal biodiesel and their corresponding limits provided by ASTM [12]

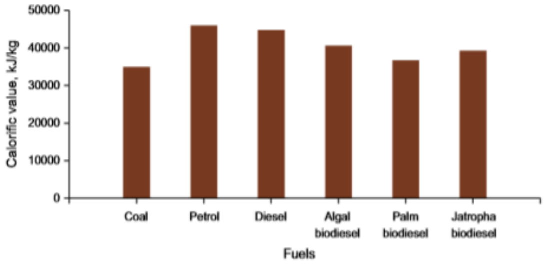

Fig 5.2Different fuels and their calorific value [12]

5.2 Emission characteristics of algal biodiesel
5.2.1 Carbon monoxide (CO) emission

According to experimenters, increase in engine load promotes a decrease in air-fuel ratio inside the engine. This stimulates an improved combustion of the fuel and sequels the formation of CO after burning. Since the biodiesel is inherited with oxygen, combustion of it is more absolute as compared to petro- diesel. So we can conclude that emission of CO through combustion of biodiesel is lower than that of diesel. Therefore, according to the above study we can say that, increased engine load is associated with gradual decrease in CO emission. The CO emission of algal biodiesel (191-30ppm) was quite lower than that of petro-diesel(560-101ppm) . The trend of CO emission in the present study is in line with similar research done with biodiesel from waste cooking oil.

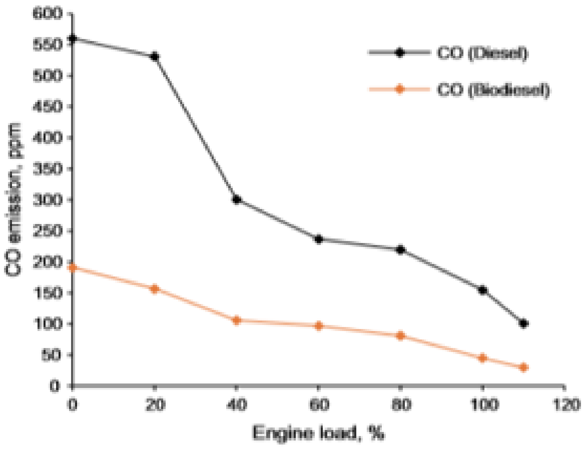

Fig 5.3 Emission of co with different engine loads [13]

5.2.2 Carbon dioxide (CO2) emission

In CI engines, as the engine load increases the amount of air-rich mixture injected in to the combustion chamber also increases. Therefore, in a CI engine the combustion of fuel is more complete under load then vice-versa. Hence, the behaviour of emission of CO and CO2 with respect to increase in engine load gives inverse results, i.e. CO2 emission increases and CO emission decreases with increase in engine load. On the contrary, for the study of CO2 this time with algal biodiesel it was stated that, CO2 emission for the combustion of algal biodiesel was lowest at zero or no-load condition, and peak emission was observed to take place at overload condition in both the cases of diesel (2.9% and 4.3% respectively). But at all load conditions of engine, emission of CO2 by biodiesel was found to be less than that of diesel. As biodiesel has lower carbon to hydrogen ratio compared to diesel, CO2 emission is higher for combustion of the latter. (Xue et al. 2011).[13]

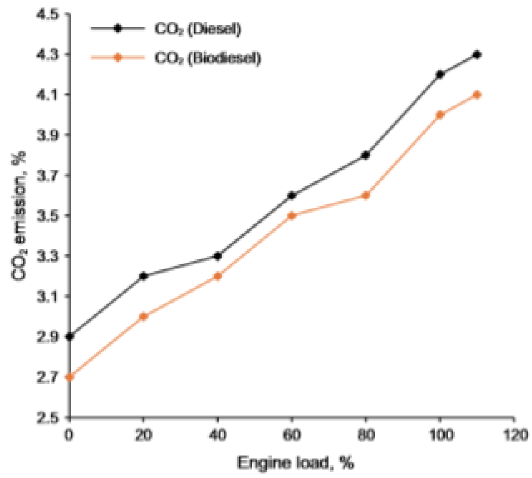

Fig 5.4 emission of $CO_2$with different engine loads. [14]

5.2.3 Emission of nitrogen oxides (NOx)

Under higher load, more heat is generated in the combustion chamber. This is why NOx emission increases rapidly with an increase in engine load. In the current experiment, NOx emission was found to increase with the engine load for combustion of both diesel and biodiesel. The emission was more in case of algal biodiesel (increased from 48 to 273 ppm) compared to petro-diesel (increased from 20 to 154 ppm) at all the engine load conditions. This may be because the in-built oxygen of biodiesel enhances formation of nitrogen oxides. Another reason for such emission behaviour might be the cylinder temperature of the engine. From it can be seen that a higher exhaust temperature was generated when biodiesel was combusted. So, it can be assumed that the cylinder temperature would also be higher when the engine would be run by biodiesel. Therefore, more NOx is produced from the combustion of algal biodiesel than from the combustion of petro-diesel. Emission of NOx can be reduced by adding favourable additives to the algal biodiesel or by placing a catalytic converter or a de-NOx catalyser in the exhaust manifold of a CI engine.[15]

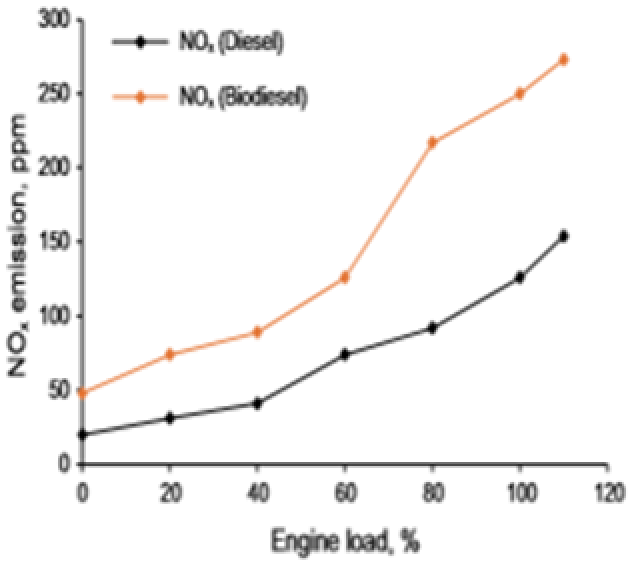

Fig 5.5 Emission of NOx with different engine loads[15]

5.2.4 Emission of unburned hydrocarbon (HC)

Emission of unburned hydrocarbon takes place due to incomplete combustion of the fuel in the engine. So, HC emission for combustion of biodiesel must be less than petro-diesel because of the presence of in-built oxygen which triggers better combustion of the former. Here also, HC emission, under all load conditions, was less for algal biodiesel than that for diesel. Emission of HC by diesel was found to decrease (from 38.9 to 25.7 ppm) withan increase in engine load. On contrary, emission of HC, by algal biodiesel, started increasing at the outset of the experiment (from 0 ppm at 0% load condition) and reached its peak (12 ppm) at 40% load and then decreased gradually up to the overload condition. According to the report of Shirneshan (2013), highest HC emission, for the combustion of waste frying oil methyl ester, takes place at 40% load and decreases gradually thereafter with the increase in engine load. This may take place because of the higher density of biodiesel than petro-diesel which results in bigger droplet size during atomization of the fuel in the engine. This bigger droplet size does not allow the fuel to burn completely, and as a result, HC emission increases. But as the load on engine increases, a more air-rich mixture (higher air to fuel ratio) is injected in the combustion chamber along with more fuel. For the presence of more air and more in-built oxygen of the biodiesel, better combustion takes place and emission of unburned HC reduces.[18]

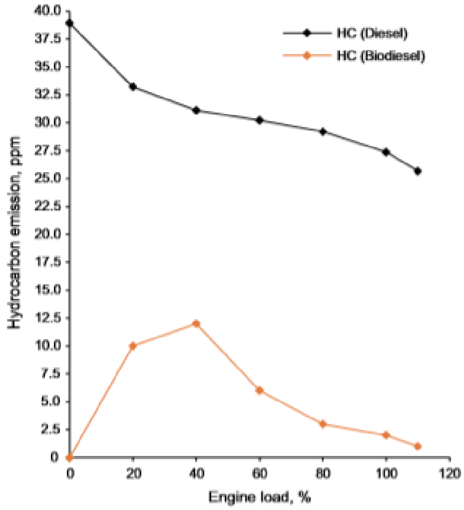

Fig 5.6 Emission of hydrocarbons with different engine loads[16]

5.2.5 Exhaust temperature

Exhaust temperature is an important feature which should be kept in account as any increase of it affects the temperature of the surrounding environment. This may exert good or bad effect on the flora or fauna of that habitat. Exhaust temperature also gives an idea of the temperature inside the engine, and engine temperature plays a very important role in emission of different gases. In the current study, exhaust temperature was found to be higher for combustion of algal biodiesel than that for combustion of the diesel and in both the cases the temperature was found to increase (41.2–59.7 C for diesel and 54.3–79 C) rapidly with an increase in engine load.[19]

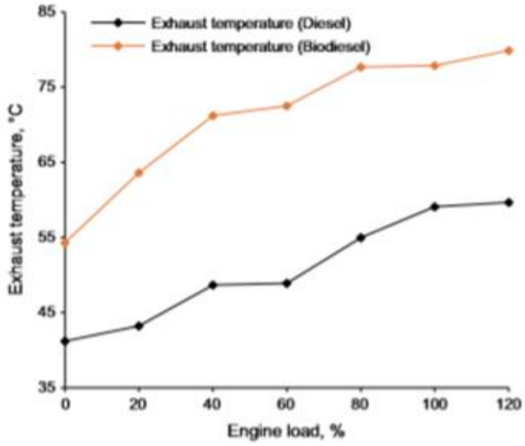

Fig 5.7 Emission of exhaust temperatures with different engine loads

VI. Conclusion

Continuous supply of diesel or its substitutes has become very important over the last few decades due to rapid industrialization and urbanization all over the globe. Depletion of crude petroleum may result in huge scarcity of this fuel future. The market price of petro-diesel is also increasing for the same reason. So, biodiesel from unused algae might be one solution to the problem as the raw material, for this fuel has no commercial value. Although the algae oil produced in this experiment has a very high FFA content, biodiesel can be produced from it by a twostep procedure. All the properties of this biodiesel were found to be within the limits of ASTM standards. So, no engine modification should be required if diesel–biodiesel blend (with lower per cent of biodiesel) is used. More study is required on engine parts to use pure biodiesel (B100) which is used in CI engines. The high calorific value of this biodiesel indicates that high power would be generated in the engine. This would help to run the engine with less fuel. It was found that only NOx emission for combustion of this biodiesel is higher than that of diesel, whereas emission of other gases like CO, CO2 along with unburned hydrocarbon, can be reduced many fold if this biodiesel is used instead of petro-diesel.[20]

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