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Research Article

Chemical extraction of Biodiesel and Parametric analysis of DI-Diesel Engine using Algae esterified Oil-Gasoline Blends

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ABSTRACT

Of late, the automobiles of all categories are massively increasing which aggravates the dependency on fossil fuel thus, the accessibility of petro-fuel decreases relentlessly. Under these circumstances, the investigations are taking new dimensions to find alternative, renewable with cost-effective fuel exclusively biofuels. However, a newer approach has been attempted for the production of biodiesel from wild stuff of Spirulina algae which is explored directly in its aquatic systems of the natural environment. The chemical extraction process was attempted with wild biomass of algae via pre-treatment for obtaining promising lipid content then; the algal oil (lipid) was subjected to the production of biodiesel through sequential transesterification reactions. The obtained biodiesel was measured as 94.65% produced from 0.920kg of algal oil extracted out of 1.6kg of algal biomass in a stipulated duration of time (2.50hr) taken for attaining maximum temperature. Further, the produced biodiesel was evaluated for its distinctive properties and the outcomes were compared with ASTM standard specifications. All the results appeared to be within the standards limit thereby, the methodical analysis was done for the performance and emission parameters via interacting algal biodiesel in the experimental (DI) diesel engine test-rig configured with a variable injection pressure of 210, 220 & 230 respectively. The blending ratio of algal diesel and gasoline (AB10 & AB 20v/v) were prepared based on volume and the results were correlated with petro-diesel. The physico-chemical parameters like color, odour, viscosity, density, total acid number, initial boiling point, flash point, calorific value, cetane number etc. were found to be significant when compared with petro-fuel. Correspondingly, the interactive parameters like flash point, pour point, cloud point, carbon residue, sulfur, ash, and water contents were correlated with the standard specifications. The substantial approach was observed in emission characteristics such as hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NOX) respectively in engine-algal fuel interactions. Whereas, a slight increase than petro-diesel with respect to sulfur oxide (SOX) emission and smoke opacity were also recorded. However, the marginal increase in Brake specific fuel consumption (BSFC) and Brake thermal efficiency (BTE) was noticed and the brake power (BP) was found slightly lower than petro-diesel. In conclusion, the protocol of producing biodiesel from wild stuff biomass of Spirulina maxima was found to be techno-economically feasible and this potential algal biodiesel can be recommended for the current engine applications without any alterations.

Keywords: Microalgae, wild stuff of Spirulina maxima, Biodiesel production, Direct injection (DI) Engine, Performance-Emission analysis, Algae Oil-Gasoline blends.

1. INTRODUCTION

The limitations of exploiting non-renewable fossil fuels are a center of attention in the world with respect to environmental protection from global warming in terms of the release of greenhouse gases, climatic fluctuations, a decline in economic growth, and steadiness followed by rapid depletion of oil reserves[1,2]. Therefore, the development of potential and alternative fuel resources is very essential for monitoring the present global energy state of affairs. The search is already scheduled for one of the promising unconventional fuel sources called biofuels which is a renewable and real-time approach [3,4]. The most recurrent biofuels comprising biodiesel, bioethanol, bio-butanol, and biogas respectively are in line with production with less expensive methods. The production of these biofuels is derived mainly from vegetable sources like soybean, Sesame, Niger, sunflower, groundnut, etc. and non-edible sources such as Pongamia, Jatropha, Simaruba, Neem, Mahuva followed by non-food biomasses, agricultural wastes, and animal wastes respectively. Despite these resources available for the production of biofuels, the factor of cost-effectiveness is needed for the hour consequently; the research community formed with scientists and technologists is, therefore, motivated to think about a range of most effective alternative sources for boosting the energy sector[5-7]. However,

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algae have been demonstrated as the best efficient resource for biodiesel at optimum level, thus algae furnished with modified protocols are of great importance in the present scenario.

However, algal biodiesel has emerged as the most practical resolution in India to corroborate the deficient components that occurred due to the scarcity of petroleum fuels. The statistics on the exploitation of petroleum products is about 125 million tons per annum as projected in the country. Interestingly, the feedstock of microalgae has been identified as it is the only source which can operate precisely to minimize the burden on petro-fuels and also cutback of the oil imports[8,9]. Besides, the obligation on the need of a very large land area can be reduced, if the algal feedstock has opted. The algae can give a good amount of oil yield per acre of cultivation even with extremely less input. It has been estimated that less than 3-4 percent of total cultivating land is adequate to produce sufficient algae biodiesel for substituting all petro-fuels being used in the country[10]. However, microalgae have been justified as a reliable source of feedstock and defined alternative to fossil-fuel by facilitating large-scale biodiesel production.

1.1. Algae: A glance on biofuel research

As a result of incessant investigations accomplished by illustrious researchers, algae are found to be the most prospective sources for mitigating the substitution of fossil fuels[11]. The higher photosynthetic competence is the predominant factor as compared to other terrestrial feedstock which is also a discrete benefit of the algal community[12]. The substantial production of algal biomass in natural habitation has already proven by its significant yields of biomass per day and per unit cropping area without placing any input and no agricultural land with a large area is required.
Furthermore, the sustainability of biodiesel production is well in line with micro-algae which are demonstrated in the process of biodiesel production, where the algae can consume carbon dioxide in the environment, where algae can captivate carbon dioxide from the air for the process of photosynthesis and replacing it with oxygen[13]. As a result, algae biodiesel plants have become very close to energy manufacturing plants that produce lots of carbon dioxide and the reprocessing of carbon dioxide by the algae community can reduce environmental pollution. Besides, the imperative approach of algae which can also generate some beneficial byproducts such as bio-manure and processed feed-stock without depleting other food sources. Further, the differential approach of algal strains with respect to appearance, color, biomass texture, cultural conditions, and chemical compositions can strongly facilitate a variable significant amount of biodiesel which can trigger efficient engine performance and exhaust gas emission while retaining superficial energy dynamics[14, 15].
The algal biofuels will have lesser impact on the environment as compared with the biodiesel derived from food producing typical crop plants. The selection of strain, method of cultivation, culturing conditions, and the chemical profile are strongly facilitating the cost effectiveness and also significantly exciting engine's performance and exhaust gas emissions[16]. The importance of the proposed study was to make an attentive analysis of the impact of the use of biodiesel produced from microalgae to the diesel engine system. There is a huge divergence in the number of papers reported on collection of algae, culturing process, oil extraction, and biodiesel production followed by overall engine performance[17]. The analytical works relating to the blending phenomenon of both biodiesel and petro-diesel is also considerably untouched as it is the most requisite approach in the automobile industry[18].

The thorough analysis of literature indicated that only a few attempts were made on different blending ratios (B5 to B50) of biodiesel and gasoline. Whereas, the tested clean biodiesel characteristics were found to be analogous with petro-diesel at B20 proportions[19]. The results also showed that some serious noxious pollutants can be reduced if the produced bio-fuels are from appropriate sources with diverse strains. Although, there was a non-significant increase of NOx which may possibly be associated with higher temperatures in the combustion chamber. Besides, the usage of additives/emulsions as a supplement to the mixture of blends or neat biodiesel exhibited a promising impact on reductions of $CO2$ and NOx[20]. However, few reports on testing engine efficiency with the blends of clean biodiesel and gasoline displayed some ambiguity results where the well-defined essential statistics on all the experiments is seriously lacking. However, the evaluation of biodiesel produced from algae conceivably is a field almost not explored accurately as the available research papers encompassing contrary results or perhaps the specific objectives are not explicitly deliberated with respect to the biofuel-engine interactive performances as this review makes evident[21].

1.2. The need for Research Intercession

The studies linking to the production of algal biodiesel, fuel mechanical properties in comparison with ASTM specifications are certainly lacking thus, this gap has to be bridged by framing the appropriate objectives[22,23]. Hence, the core objective of the current study was to analyze the efficiency of algal oil in association with blending performance in the experimental engine system. The physico-chemical characteristics of the algal esterified oil were decisively assessed and the promising blends were subjected to parameterize the

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virtual enactment of a diesel engine for performance and emission characteristics and were also critically evaluated through a comparative approach in the engine system running on algal biodiesel. Some of the previous research works on algae source concerning their types, growth attributes, processing for biodiesel production, optimization parameters followed by engine interactions were prominently discussed in the following review studies.

Therefore, in the recent scenario, the effectiveness of Biodiesel derived from algae source has been considered as a substitute to the other renewable fuels which are based on their diverse characteristics such as performance, emission, and combustion coupled with steadiness in the engine interaction with the fuel. Initially, combustion is a crucial process which helps in evaluating the feasibility of the tested biofuel as well as overall competency of the engine. Further, the crucial factor is validating performance characteristics like, thermal efficiency, engine power, specific fuel consumption, torque, brake power, respectively.

Finally, the emission properties are concerned, environmental approval is a strategic aspect for selection of fuel and gratification of environmental regulatory norms which are deliberated exclusively for exhaust gases[23].

Hence, the review of literature consistently reveals that many researchers have experimented on diverse range of engine system using different blending ratios (5% to 100%) of biodiesel by weight/mass and this has molded some unpredictable outcomes that are difficult to compare the overall performance of the engine system. Consequently, the literature analysis on engine performance has been represented in a tabular format for having critical analysis and also for better understanding on the engines of variable configuration. Thus, the previous studies carried-out on the production of Bio-fuels from different bio-resources followed by biofuel-engine interactions are analytically deliberated hereunder.

1.3. Recent investigations on the production of Bio-fuels from different bio-resource samples

Feedstock	Objectives focused	Major findings	Ref.
Microalgae *Spirulina platensis*	To assess fuel properties for microalgae biodiesel and its blends with Egyptian petro-diesel were analysed.	All the characteristics were closer to the standard range with competence. The outcome was significant.	[24]
Green algae (*Chlorophyceae*)	To appraise the performance and emission characteristics of Algae Bio-fuel supplemented with additives using blends of biodiesel & diesel fuel.	The Performance was accelerated admitting with low emission. Biodiesel- diesel blends with nanoparticles were attempted to get a little modified fuel. Results on performance and Emission tests are compared for both fuels.	[25]
Sunflower oil	To achieve production & optimization of Biodiesel by RSM approach. CI engine was interacted with blends of biodiesel & diesel fuels for assessing its performance and its emission characteristics.	The blending of B5, B10, B15 (biodiesel with diesel fuel) were found to be significant in decreasing harmful gas emissions while maintaining equivalent performance output and efficiency.	[26]
	To evaluate performance of Algae oil using Diesel Engine system configured with different Injection pressure.	The superior performance in the diesel engine as well as reduced emission characteristics was noticed with change in injection pressure of AME20.	[27]
	To know how the performance and exhaust emissions in the Diesel Engine adopted to interact with blends of algal biodiesel-diesel *i.e.,* B10, B20 respectively.	Similar approach of physico-chemical properties in blends of biodiesel (B10 and B20) was observed. B20 blend displayed a considerable decrease in specific fuel consumption & exhaust gas temperature, similarly, a substantial increase in B20 than B10 blending was noticed in thermal efficiency. The emission gas was reduced considerably at B20 compared to B10 blending ratios of both fuels. The superior grade of biodiesel can be achieved from microalgae *S. obliquus* and may recommend the same with eco-friendly approach in the conventional diesel engine system.	[28]

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Spirulina maxima algae	To Optimize Biodiesel production from *Spirulina maxima* microalgae and testing of performance in a diesel engine.	The physico-chemical properties of the optimized biodiesel were equated with the ASTM D6751 standard specification and found to be justified as it is closer to petro-diesel. The unmodified diesel engine interacted with biodiesel blends of both 20 % and 40 % (v/v) for its performance and emission tests which showed significant as a whole when compared with Diesel fuel outcomes. But, the amount Nox found to be little higher in biodiesel than petro-diesel which is due to presence of more oxygen within it. This may leads to complete combustion of the fuel and inturn raises the temperature of products.	[29]
Microalgae	To cultivate microalgae for the production of biodiesel by employing both upstream and downstream techniques.	Microalgae require less land as compare to other feedstock. The cultivation practice of algae found to be more economical compared to other feedstock.	[30]
Non-edible Oils	To appraise the efficacy of additives supplementing with biodiesel fuel to enhance the combustion and performance followed by reducing the emission using direct injection diesel engine.	The employing of selected additives with variable specifications *i.e.,* metal-based, cetane number, antioxidant, & oxygenation facilitated the improved characteristics of biodiesel. But, the use of additives will affect the cost effectiveness of the biodiesel.	[31]
Microalgae, fossil diesel, and Soybean Methyl Ester	To analyse performance & emission characteristics of microalgae fuel using combustion engine system. The esterified oils of microalgae, soybean methyl ester and blends with fossil diesel are used.	Lower power & torque to some extent, More SFC, reduced NOx & PM at lower blending ratio. İn all, it was compatible with petro-diesel	[32]
Microalgae	To assess the efficiency of microalgae biodiesel and biodiesel from vegetable oils is also attempted.	Comparatively, algae displayed more economical than other feedstocks.	[33]
Vegetable oil and animal oil	To understand the efficacy of vegetable oils supplemented with new solid catalyst for enhancing the Biodiesel production *via* transesterification.	Increase BSFC & BTE and reduction in HC & CO and the other related parameters are within the acceptance range. But, the economics of the biodiesel derived from animal oil has to be viable	[34]
Algal biomass	Production of Biodiesel from algae and suggesting it as an alternative fuel for Diesel	The characteristics analysed were within the range of ASTM standards and were comparatively analogous. The cultural segment has to be reformed.	[35]
Algae Oil	To analyse the characteristics of performance, emissions, sound and combustion in Algae oil Biofuel.	The increased oxides of carbon and decrease of nitrogen, hydrocarbons were noticed at lower fuel blends.	[36]
Soybean, Rapeseed, Cottonseed, Palm oil, Peanut + sun-flower, Mineral Diesel	To evaluate spray, combustion, performance, and emissions characteristics of Biodiesel fuelled engines by Computational approach.	The results are found to be within the genuine range except some differential approach in emission properties. İn addition, the edible oils are not viable as these sources have food cum medicinal value. So, non edible oils are suggested.	[37]
FAEE, FFA, Glycerol, Triglyceride	To know-how the consequences of producing biodiesel from acidic oil using sulfuric acid and calcium oxide as catalysts with techno-economic feasibility.	Acidic oil using sulfuric acid and calcium oxide are used as catalysts are employed. The Catalysts showed improved performance of the engine. Additives needs to be stndardized.	[38]
PME RME SME TME	To study the parameters such as cetane number, density, kinematic viscosity, and heating values from their respective fatty acid compositions to attain biodiesel.	The data was found to be compatible in line with cetane number and density. But, heating values and kinematic viscosity were found to be Poor.	[39]
ALGAE Methyl Esters	To study the characteristics of algae biodiesel by experimental engine test rig.	BTE & SEC were comparable, but CO_2 was increased and both CO & NOx reduced. The rate of heat release was also found to be compatible with respect to engine efficiency.	[40]

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Algal feedstock	To investigate the blends of Algae oil-Gasoline for its performance at variable compression ratio (VCR) Spark Ignition Engine.	Algal-fuel blends showed increase in BSFC and reduction in BTE thereby engine peroformance was found to be significant.	[41]
Algal biomass (Unused)	To study the magnitude of biodiesel production from unused algae and analysis of fuel & emission characteristics.	The results were found to be within the ASTM standards with respect to fuel performance and emission properties. CO, CO_2 & HC were reduced and higher Nox was noticed.	[42]
Algae Oil	To analyse the characteristics of Performance and Emission in VCR Diesel Engine interacted with Algae Oil.	Algae-20 has showed better engine performance and the exhaust characteristics were found to be marginally reduced.	[43]
Biodiesel from Freshwater Algae	To study the performance of CI Engine at different compression ratio fuelled with freshwater algae biodiesel.	The blends of both B10 and B20 fuel are recommended as ideal proportions for CI Engine system. The results of both B10 and B20 algal blends were found to be closer to that of petro-diesel relating to overall performance characteristics.	[44]
Rubber seed oil	To produce of biodiesel using rubber seed oil by catalysed transesterification processes	By varying the reaction mixture, biodiesel has been achieved to a significant level.	[45]
Vegetable oils	To determine the response in vegetable oils added with a new solid catalyst for enhancing Biodiesel *via* transesterification.	Cracking and hydrocracking approach by the role of heterogeneous catalysis is noticed, thus, the process can be employed to exercise vegetable oils into fuels with deoxygenated hydrocarbon	[46]
Bio-fuels (Nine varieties) and pure diesel.	To study the characteristics like, performance, combustion, and emission of various biofuels through numerical investigation.	Nine different alternative biofuels along with petro-diesel were employed. The efficacy of biofuels has been justified for exploring as alternative fuels.	[47]
Microalgae	Assessment of combustion characteristics of engine fuelled with sustainable biodiesel with respect to magnitudes of injection timing and pressure.	Injection timing and pressure on CI Engine was recorded and the results are quite closer to petrodiesel	[48]
Microalgae	To review the prospective approach of microalgae to bio-fuels: Objective of Promising alternative and renewable energy	Review substantiated that; the algae will be a better option for alternative fuel.	[49]
Microalgae	To evaluate the effect combustion, performance, and emission characteristics of Microalgae Biodiesel using a Diesel Power Generator.	The algae oil can be used as fuel in Diesel Power Generator. Combustion, Performance and Emission Characteristics were found to be significant.	[50]
Microalgae	To know the performance and emission properties using a compression ignition engine. To analyse the effect of antioxidant additives with biodiesels for refining the parameters.	Treating biodiesel with antioxidant additive was found to be a promising approach for reducing NOx emission. In conclusion, performance is improved and emissions are reduced.	[51]

On account literature survey, it was apparent that the number of research investigations demonstrating the use of algal oil with engine interaction and its performance appear to be scarce and abridged to know-how the mechanism of fuel competence with the existing engine system. The exercise of algae esterified oil may conquer the difficulties relating to the practice of overpriced chemicals and laborious processes during the reaction of the transesterification process are of the most considerable factors for having sustainable production of biodiesel.

1.4. About Spirulina algal wild stuff

The search is on for documentation on diversified algae and their respective species at their natural origin and also monitoring of the conservation of algal diversity at their natural habitat. This database will make it possible to obtain desired algal types for biodiesel production[52].

The algal wild stuff collected in the study area was Spirulina is explicit biomass belongs to the group Cyanobacteria (blue-green algae). For a long time, Spirulina was regarded as algae. However, it is now known that it is a bacterium, thereby it can be able to perform photosynthesis; subsequently, it is classified as Cyanobacteria. This alga is found in ponds, lakes with increased pH. Therefore, it can only survive in alkaline waters, with a pH between 10 and 11. The algae Spirulina was found to be most viable for biodiesel production as it is having significant lipid contents in its biological organization[53,54].

The contemporary use of this biological resource has three patterns: traditional, scientific, and technological development, and the so-called green tendency. Spirulina is being cultured in vitro under controlled conditions. But, it has been focused to maintain and motor the wild stuff culture at its natural habitat

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followed by attempts with the cultural approach in large at its natural environment such as outdoor ponds, lakes, streams, trough/gully; other desired waterway channels under moderate-controlled conditions[55,56]. On the other hand, it is now widely cultured throughout the globe as a most stabilizing component with health benefits in a variety of human foods and animal feeds. Currently, the production of *Spirulina* worldwide is projected to be about 3000 metric tons. Besides, the market value of *Spirulina* is considerably high (70%) which is exclusively for human consumption in terms of healthy food supplemented with rich content of protein followed by essential amino acids, vitamins, essential fatty acids and minerals[57, 58].

In the Open System of Natural habitation (OSNH), it was found that the of S. maxima algae was most abundant in its natural ecosystem with respect to its production with the minimum technical strategies which can facilitate the significant production of *S. maxima* in its natural region like, controlling the culture temperature, minimizing production cost and displaying climatic data-based Habitation information modelling (HIM) cluster in their natural environment[59,60,61]. Hence, the proposed approach would be distinctive with significant objectives that can reduce the burden on culturing constraints of algae *in vitro*. However, the main focus of the current study is to produce biodiesel from algae wild stuff via chemical extraction methods and to analyse the efficacy of the algal oil with respect to performance and emission characteristics using a diesel engine experimental test rig at variable fuel blends.

2. MATERIALS AND METHODS

The wild stuff of *Spirulina maxima* algal material was collected productively in its natural origin at different locations of Devarayana Durga, Tumakuru district, Karnataka during 2019-2020 (Fig. A & B). The variability of algal samples in their growth expressions, were compared between two geographical regions *i.e.,* Ranchi, Jharkhand state and the Tumakuru & Mysuru (southern part) of Karnataka, India.

2.1. Materials

Pure sodium hydroxide as an alkaline catalyst, anhydrous sodium sulfate, chloroform, and methanol was procured from Merck Co. (Mumbai). All other chemicals used for the preparation of cultivation medium were of analytical grade. A commercial Gasoline/petro-diesel sample was obtained from a local fueling station. Besides, highly pure analytical grade chemicals were selected for this investigation: 99.8 % pure CH_3OH (methanol), 96 % pure H_2SO_4 (sulphuric acid), 86 % pure KOH (potassium hydroxide), diethyl ether, methylene chloride, n-hexane.

2.2. Classification of collected Microalgae

The collected algal sample was thoroughly analyzed using a light microscope and the characteristic features were assessed by means of standard references. Besides, the quantifiable observation of algal mass was done with plankton-counting cell method (Sedgwick rafter). Later, citation of algae was accomplished in accordance with the distinctive methods for ensuring its taxonomy[62,63].

2.3 Collection of Algal feedstock & pretreatment

The water samples with a visible micro-algal population of *Spirulina maxima* were collected from ponds, lakes, temple tanks, and rivers that are located in and around Devarayana durga a divine hill station of Tumakuru district (Karnataka), India. The wild stuff of *Spirulina maxima* was obtained openly from its natural habitat and the sample was then subjected to pretreatment. Primarily; the algal sample was properly washed with fresh water, dehydrated under shade, and subjected for heating in the oven at 70°C for complete removal of moisture. Subsequently, the dried algal biomass was made into fine powder using a mechanical grinder and the sample was mixed with water in 1:3 (v/v) ratios. Later, the cell destruction of the algae biomass was facilitated using an ultra-sonication process unit adjusted with 24 kHz frequency and 50°C temperature were monitored for 5-8 minutes. Then the sample was made ready for extraction of oil proceeding in line with biodiesel production (Figure 5A-F).

METHODS

2.4. Extraction of Oil from Algal sample

The pre-processed biomass of *Spirulina maxima* wild stuff was ground into a homogenous fine powder using a mechanical grinder and the dried cells of algae were mixed with the solvent system comprising of Hexane and Iso-propanol (3:2 v/v ratio). Then, the homogenate mixture was put into a soxhlet apparatus fitted to a round bottom flask and together with a magnetic stirrer. The cell residue was detached by the filtering process at 30°C for 2hr and the filtrate was transmitted into a separating funnel and sufficient water was added to induce the formation of a biphasic layer. The solvent mixture was partitioned soon after settling into two distinct phases, the top dark green hexane layer having most of the extracted lipids and the bottom light green layer containing most of the co-extracted non-lipids. Finally, the hexane layer was collected in a pre-weighted flask and subjected for evaporation using a rotary evaporator[64,65].

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2.5. Algal oils to Biodiesel production

The production of biodiesel was performed through time and temperature based receptive reactions called esterification and transesterification processes. The esterification reaction was carried-out using 98% acid catalyst, (H_2SO_4) and 100% lipid-derived from algal mass (wild feedstock), in the meantime, methanol (CH_3OH) was added and the ratio of alcohol/lipid was 50:2 (vol./wt.). Methanol (50% of the consigned volume) was added earlier to facilitate the dissolution of oil and the remaining 50% of the methanol was mixed with an acid catalyst followed by a total reaction component. The reaction was carried out at 60°C for 3 hours duration in continuous stirring using a water bath equipped with reflux system. The surplus alcohol was removed after the completion of reaction by evaporation using a rotary evaporator. Further, the esterified oil was subjected to a transesterification reaction with a base catalyst (NaOH/KOH) using methanol, and the rest of the reaction will be performed with the algal feed-stock as explained above.

2.6. Esterification of *S. maxima* algae crude Oil

Theoretically, it comprises two-step reaction processes, where, the esterification was performed at the initial stage with an acid catalyst (H_2SO_4), using a suitable glass reactor for the production of biodiesel. This has been explicitly recommended when the algal oil consists of a high content of Free Fatty Acid (FFA) which is above 2%. The esterification process facilitates the reduction of FFA in algal Oil which will be preventing the formation of emulsified soap as it will be inhibiting the yield of biodiesel at the end. Hence, the two-step process for the production of biodiesel has been carry out. Therefore, in the esterification reaction, H_2SO_4 (1.5%v/v) and 12:1 methanol to oil molar ratio with 500rpm stirring speed at 60^0C temperature for about 90 min duration were monitored [66, 67]. Finally, the esterified oil was separated through a separating funnel and the FFA (%) was found to be reduced from 5.9% to 0.450% (Fig. 1).

Further, the esterified oil will be subjected to a transesterification process using an alkali catalyst (NaOH/KOH).

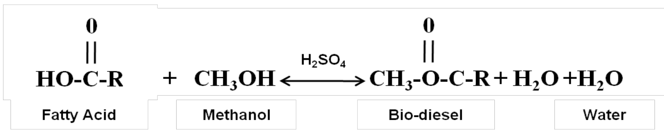

Figure 1. Esterification reaction with an acid catalyst

2.7. Transesterification of *S. maxima* algae Oil

Subsequently, the second stage of reaction is the transesterification process which is performed as a major step of biodiesel production. The esterified oil was transferred into the glass reactor and subjected for heating at 60°C. The base catalyst, KOH was prepared in a separate flask with methanol at different concentrations and the molar ratio was taken (Fig.2).

Subsequently, the methanolic KOH was subjected to heating up to 60°C and this was mixed with the algal oil. The reaction mixture was set aside for the period of 90 min to carry on the reaction and allow settling for 2 h in a distinctive funnel to separate the layer of biodiesel (top layer) and glycerol (bottom layer). Meanwhile, the optimizing reaction parameters like, biodiesel yield, molar ratio, amount of catalyst, temperature, reaction time coupled with a stirring speed were recorded at variable settings[68, 69,70]. At last, the upper layer containing biodiesel and a lower layer having glycerol was successfully divided. The Biodiesel was then subjected to the purification process and the glycerine was stored in a suitable container as it is having a value addition in soap industries.

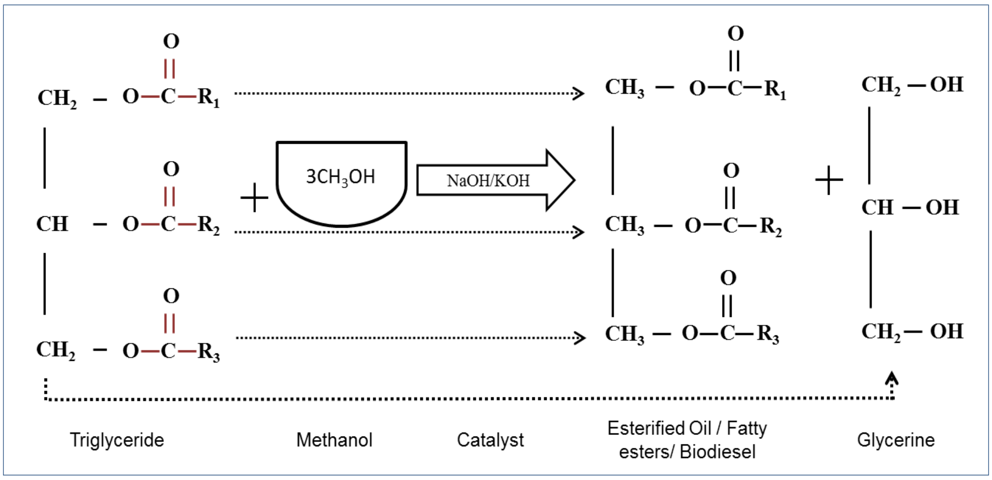

Figure 2. Transesterification reaction (R1, R2, and R3 are long-chain hydrocarbons/fatty acid) with the base catalyst

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2.8. Determination of Biodiesel Yield (%)

The yield of Biodiesel (% w/w) was measured by the following standard formula (69).

$$\text{Biodiesel Yield (\%)} = \frac{\text{Weight of the biodiesel produced (g)}}{\text{Weight of the algal oil used (g)}} \times 100\%$$

2.9. Designing of Experimental Engine Test rig

The biodiesel from the Microalgae sample was subjected to interaction using a Diesel Engine having requisite configuration[71]. The engine test rig was designed based on the parametric objectives projected in the experiment. The specification consisted of a direct injection (DI engine) diesel engine provided by Kirloskar TV-I (Table 4). The experimental engine test rig was accomplished with a single-cylinder and 4-stroke water-cooled system having 3.4 kW brake power at a constant of 1600 rpm. In addition, the engine was further connected to an eddy current dynamometer provided with a well-acquainted controlling system. The engine test rig was compatible with elegant sensors for piezo-type cylinder pressure, crank angle, thermocouples to measure the temperature of the water, air, and exhaust gas respectively. Besides, a di-gas analyzer was affixed to measure the emissions from the exhaust gas. Besides, the smoke density from the engine exhaust gas was analyzed using AVL smoke meter[72,73]. The graphic diagram of the engine test rig has been represented (Fig. 3).

The DI-engine test rig was interacted with the clean algae oil-gasoline using a set proportion of fuel blends at a constant speed of 1600 rpm and the engine was allowed to run for 25 minutes till attaining a steady-state condition. The efficiency of the engine test rig for its objectives connected with range at variable loads and at each load, rate of airflow & fuel flow was measured. The exhausts gas temperature; oxides of nitrogen, carbon monoxide, unburnt hydrocarbon and smoke density were systematically recorded[74].

The tangible experiment with all the equipped configurations of engine test rig was performed to examine the efficacy of algae oil-gasoline blends of AB10 and AB20 respectively. The parametric analysis relating to the performance and exhaust emissions of the diesel engine was evaluated and the results were compared with diesel fuel. Further, observations were recorded after the engine reached its steady-state condition and then, the engine was re-stabilized before the operations at each trial. The trials were repeated and systematically monitored to ascertain the readings generated from experimental investigations.

The engine speed was constantly maintained at a speed of 1600 rpm at each engine load. The performance oriented parameters such as engine power, thermal efficiency, specific fuel consumption, air-fuel ratio followed by exhaust gas temperature and volumetric efficiency were evaluated. The analysis on emission parameters such as CO, CO_2, NOx, and HC were executed and the results were systematically recorded[75].

All the data were analyzed with ANOVA two way interaction test for the parameters and the features found to be significant ($p \leq 0.05$).

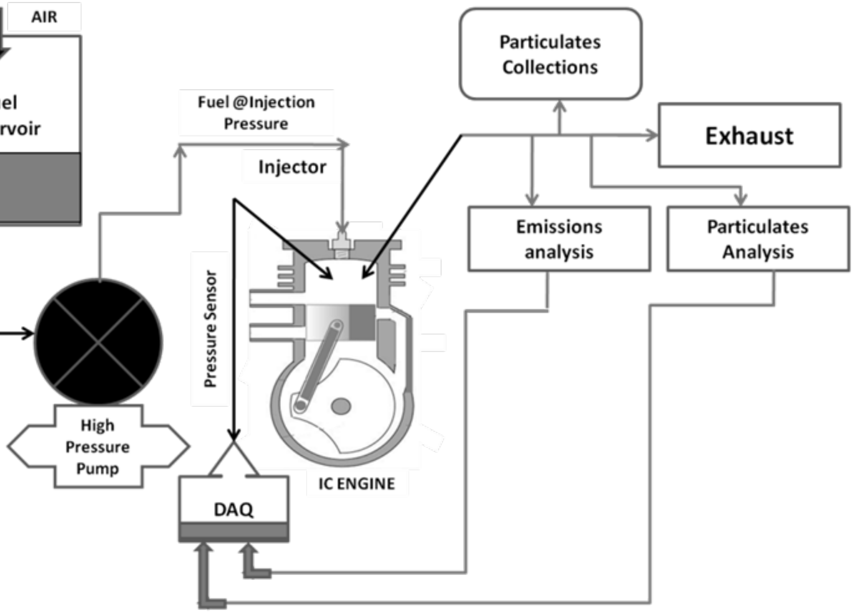

Figure 3. Schematic showing engine testing experimental layout

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3. RESULTS AND DISCUSSION

The analytical study was carried out in association with the Bio-energy Research division of Hamsa Research Foundation, Tumakuru during 2019-2020 in association with Azyme Biotechnologies, Bengaluru. The qualitative parameters were analyzed at Chemistry Research Laboratory, University department of Chemistry, Ranchi University, Ranchi, Jharkhand State, India.

3.1. Collection and Classification of Microalgae

The algal feedstock collected as wild stuff of algal biomass directly in the natural habitat during the baseline survey was identified as Spirulina maxima in its natural habitat (water bodies located near Devrayana Durga, Tumakuru district, Karnataka). The identification of algal species normally necessitates a concoction of both morphological and genetic description. The onsite morphological identification was done for the wild culture sample using a dissection microscope followed by a compound light microscope which was done using the standard method[76,77]. The collected sample was intact mass with lush green and found to a significant algal wild stuff material presented in Figure 4A-F.

3.2. Production of Biodiesel via Transesterification reaction

3.2.1. Algal biomass yield

The collected huge mass of *Spirulina maxima* wild stuff was processed as per the standard procedure and after drying, a substantial reduction in the weight of algal feedstock was noticed. The estimated dry weight of the *S. maxima* algae was 1.25 to 1.60 kg for every 10 kg of wet algal biomass (Table 1). The algal mass after processes looks sizably thin & slightly dark green liquid and the quantity oil obtained was 0.920 kg and the final recovery of biodiesel was found to be 94.65 (%) (Figure 4C and Table 1).

3.2.2. Oil generation form Algal biomass

The fine-tuned and weighed algal biomass was subjected for oil extraction and the generated oil in weight per kilogram of dried biomass was calculated using the standard formula (Table 1).

$$\text{Oil yield} = \frac{\text{Oil extracted}}{\text{Algal dried biomass taken}} \text{ X } 100$$

The oil from algal biomass was obtained through solvent extraction (hexane-9%) where the volume of hexane was higher out of two solvents used in the extraction process. In addition, acetone was preferred to extract algal oil (8.5%) as it is economically viable compared to hexane (Table 1).

3.3. Transesterification and Biodiesel production

The algae oil accomplished through chemical extraction was subjected for transesterification processes to achieve biodiesel. When the algal biomass was processed into the pre-esterification method, the significant reduction of free fatty acid (FFA) was observed. Subsequently, the transesterification process was employed to enhance the quantum of biodiesel where all FFA will be converted into esterified oil *i.e.,* biodiesel. As per the protocol, the yield of biodiesel along with crude glycerol was measured by their weight corresponding to the weight of algal biomass which was found to be around 16% and 3.45% (wt%), respectively. The FAME composition of the algal diesel achieved and its profile was compared with the common fatty acid outline that has been compared with other biodiesel. The produced algal biodiesel was analyzed based on its distillation approach as well as its fuel properties and compared with petro-diesel as per the ASTM standards. The data of algal diesel characteristics are found to be significant and are most acceptable as the statistics meet most of the specifications. Hence, the biodiesel resulting from algae wild stuff can be graded as a most reliable fuel and the same can be recommended for its use in automobiles as a potential alternative to petroleum-diesel (Table 2).

3.4. Blending of Algal Biodiesel with Petro-diesel

The algal biodiesel was then subjected to blending with petroleum diesel to test the efficacy of the engine, so the algae esterified oil with petro-fuel in the ratio of AB10, and AB20 were prepared respectively. The Kinematic viscosity for fuel blends of AB10 and AB20 was found to be 4.26 and 4.87 CST @ 40º C. subsequently, the Net Calorific value of AB10 and AB20 blend was 41019 and 45787 kJ / kg recorded. However, it is evident from the experimental investigations, the properties of the biodiesel and their blends are found to be very close to the petro-diesel therefore, it can be used in the existing engine system (Table 3).

3.5. Chemical and Mechanical properties of Biodiesel

In all, the obtained data on physico-chemical properties by means of viscosity, density, flash point, cetane index and heating values of algal biodiesel with their blending proportions of AB10 and AB20 were analogous to the diesel fuel. The crucial parameters were very close to ASTM standard values. The viscosity of algae diesel blends of AB10 and AB20 were found to be higher than diesel fuel; nevertheless, it was meeting with ASTM standards values. The higher viscosity in fuel is generally unsuitable for use in diesel engines due to

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inefficient atomization. However, the heating values of AB10 and AB20 biodiesel blends were within the acceptable limit of diesel fuel. In addition, the flashpoint values of biodiesel blend AB10 and AB20 were higher (80.50 and 89.6) than diesel fuel respectively. This facilitates the safer handling and storage of biodiesel than petroleum-fuel. Further, the blends of AB10 and AB20 showed the Cetane Index of 52.6 and 64.24 respectively and were significant to touch the minimum prerequisite of diesel fuel (Table 3).

Therefore, it is appraised that combustion efficiency and fuel quality parameters were higher than that of diesel fuel. It could be concluded that the fuel properties of S. maxima algae biodiesel are placed almost within the suitable range and commended limits[61]. This is in accordance with the previous report made on Chlorella biodiesel with respect to its physico-chemical characteristics. In comparison, the biodiesel derived from both algae exhibited analogous properties with considerable variations. But, the properties of S. maxima biodiesel justified with ASTM standards were found to be clean with superior quality and sustainable biodiesel.

3.6. Analysis of diesel and biodiesel

The production of biodiesel with a maximum yield was explored from the algae oil obtained from algal biomass collected directly in the natural habitations (Table 1). The blends of algal diesel exhibited a higher viscosity than diesel fuel and the higher calorific value (43.23 MJ/kg) of the algal biodiesel was recorded as compared to petroleum-diesel. The Cetane number (CN) of the biodiesel and its blends was comparatively higher than diesel fuel. The acid value of the algae diesel was found to be significant and the higher oxygen content of algae-oil is more attractive for the production of automobile fuels. The moisture and carbon residue content was 0.04 % and 0.045 %wt., respectively. The analyzed properties of biodiesel and diesel were found within ASTM standard limits (Table 3).

Further, the experimental engine test rig was designed and the required specification has been given in Table 4.

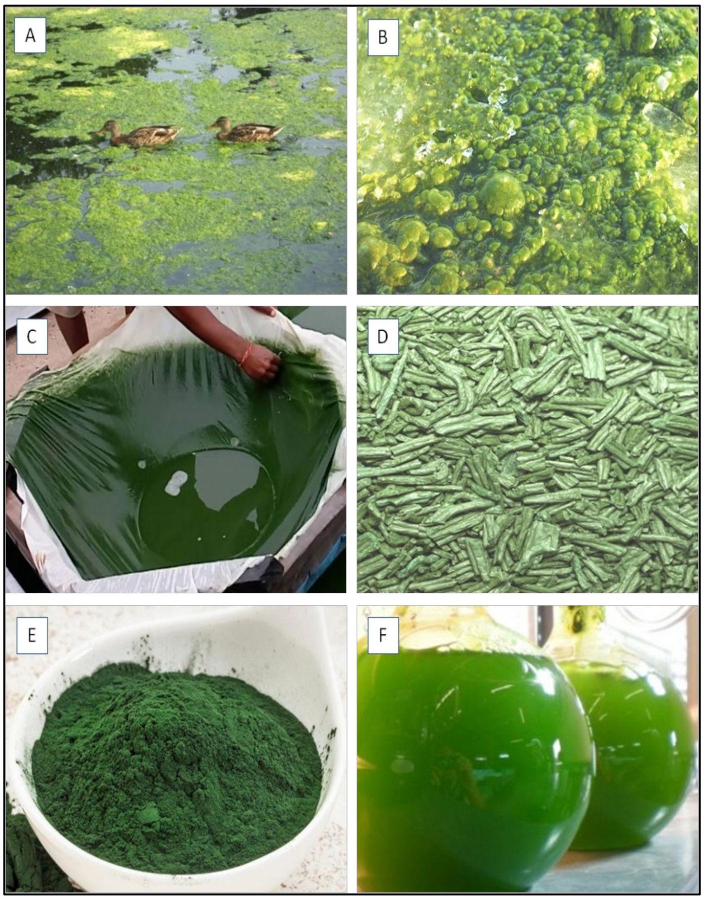

Figure 4. **(A-F). *Spirulina maxima*- the stages of wild stuff to biodiesel**

- **A.** The feedstock of *S. maxima* at Lake,
- **B.** Closer view of *S. maxima* wild stuff Sample in its habitat,
- **C.** Extraction of Algal sample,
- **D.** Algal sample air dried,
- **E.** Powder sample of *S. maxima* and
- **F.** Algae Oil

Table 4. Specifications of Experimental Engine Test Rig

SL. No.	Engine parameters	Specifications
1.	Production Industry	Kirloskar
2.	Cylinders number	Single cylinder
3.	Cycle	Four-stroke
4.	Cooling system	Water-cooled
5.	Cylinder diameter (mm)	90
6.	Piston stroke (mm)	120
7.	Compression ratio	17:1
8.	Rated speed	1600 rpm
9.	Maximum output	7.5 hp

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Table 1. Preliminary Physico-chemical analysis of *S. maxima* algae Oil and Biodiesel production

Algae type	Sample Type	Appearance	Moisture (Wt %)	Temperature (^{O}C)	Biomass of Algae (Kg)	Time engaged for max Temp.(hr)	Quantity of Oil (Kg)	Biodiesel Recovery (%)
Spirulina maxima	Wild-stuff	Thin & slightly dark green liquid	0.062	60-90	1.6	2.50	0.920	94.65

Table 2. Analysis of characteristics of Biodiesel derived from *S. maxima* algae

SL. No.	Properties	Crude Oil	Algal diesel	Limits (ASTM)
1.	Density (kg/m3) at 15^{0}C	1.026	0.882	0.87-0.89
2.	Higher heating value (MJ/kg)	46.5	40.8	--
3.	Kinematic Viscosity (mm^2/s) @40^{0}C	37.45	4.82	1.9-6.2
4.	Carbon (wt%)	78	86	--
5.	Hydrogen (wt%)	≤10,5	≤12,6	--
6.	Oxygen (wt%)	≥10,3	≥11,4	--
7.	Sulphur (wt%)	0	0	<10 max. 0,03
8.	Higher calorific value (MJ/kg)	nd	43.23	46.56
9.	Cetane Number (CN)	nd	47	na
10.	Acid value (mg KOH/g)	11.435	0.524	0.50 max.
11.	Iodine value (IV)	84.24	nd	na
12.	Saponification Value (mgKOH/g)	188.92	nd	na
13.	Flash Point (0C)	nd	189	130 max.
14.	Pour point (°C)	-14	-13	--
15.	Cloud point (°C)	-	1	3 (maximum)
16.	Carbon Residues (wt%)	nd	0.0412	0.050 max.

Table 3. Analysis of chemical & mechanical properties of Algal diesel (*S.maxima*) blends AB10 and AB20 comparing with diesel fuel and ASTM standards

SL. No	Properties	Method	ASTM D-6751-02 Standard	Diesel oil	Blend of Algal diesel (*S.maxima*) (AB10)	(AB20)
1.	Density @ 15 °C	ASTM D-4052	0.880	0.838	0.869	0.886
2.	Kinematic viscosity, CST @ 40° C	ASTM D-4450	1.9-6.0	1.97	4.26	4.87
3.	Heating value (kJ g^{-1})	ASTM-D975	-------	--------	38.51	41.45
4.	Flash point, °C	ASTM D-93	>125	75	80.5	89.6
5.	Cetane Index	ASTM D-976	> 47	69.75	52.66	64.24
6.	Gross Calorific value GCV (kJ / kg)	ASTM D-225	--------	45401	43224	46454
7.	Net Calorific value NCV (kJ / kg)	ASTM D-225	--------	42670	41019	45787

Table 5. Emission properties of algal Biodiesel in comparison with Petroleum diesel

SL. No	Fuel Type	Emission Characteristics				
		CO (%)	CO_2 (%)	NOx (ppm)	HC (ppm)	O_2 (%)
1.	Algal diesel *(S. maxima)*	0.076±0.002	3.942±0.024	20.70±1.266	12.76±0.44	15.6±0.000
2.	Petro-diesel	0.103±0.02	4.245±0.00	22.80±1.71	27.65±0.01	16.4±0.02

The outcomes of the previous literature review and the results of present study both indicate that algal biodiesel has enormous potential as a future fuel source. The data on emission parameters were documented from a diesel ngine in operation at about 3000 rpm for the time duration of 10min. The standard average data was recorded at 60 seconds of interval where the exhaust emissions were at a steady state and was revealed together with the standard deviation (±). However, the

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emissions data was corresponding to a percentage of the total gas followed by parts per million (ppm). 3.7.

ANALYSIS OF ENGINE PERFORMANCE

The experimental investigation was carried out with the picture-perfect configuration. The testing was executed for a blending proportion of AB20% with neat diesel fuel using various injection pressures (210 bar, 220 bar, and 230 bar) respectively.

3.7.1. Brake Thermal Efficiency (BTE)

In this parameter, the idiosyncratic curve of brake power against the brake thermal efficiency was observed and it was also noticed that, more or less all the parameter were lies with the same trend. Whereas, the brake thermal efficiency was pronounced a slight increase for AB20 at 210 bar injection pressure up to part load. Subsequently, the increase in brake thermal efficiency for AB20 fuel along with the varied injection pressure was noticed (Fig. 5).

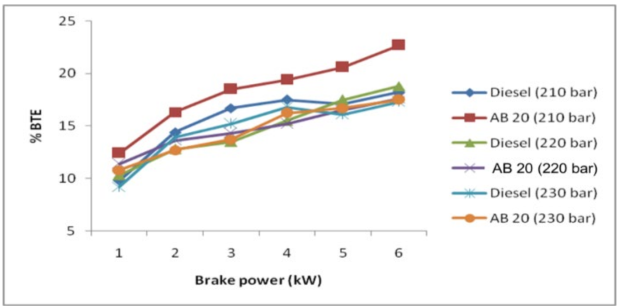

Figure 5. Brake Power v/s Brake Thermal Efficiency in Fuel blend of Algal diesel-petro-diesel at variable injection pressure

3.7.2. Engine Power (EP)

The algal oil exhibited lower engine power compared to petro-diesel; this is due to the lower heating value of the algal diesel when it is subjected alone. When the algal diesel is subjected to an experimental engine test rig with different blending proportions of petro-diesel then, the engine power can be monitored significantly at required level (Fig. 6).

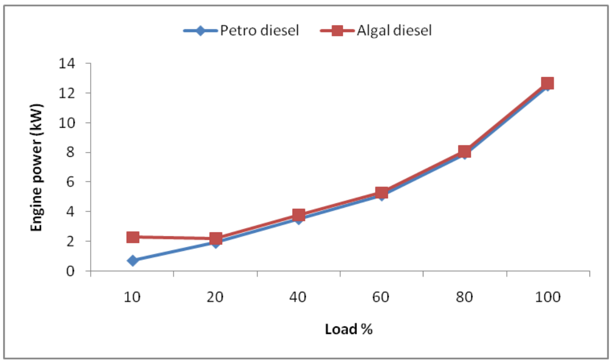

Figure 6. Engine power in Fuel blend of Algal diesel-petro-diesel at variable loads

3.7.3. Brake Specific Fuel Consumption (BSFC)

The higher brake fuel consumption (BSFC) at lower loads was recorded for algal fuel, whereas; the difference was lesser at higher loads which were also treated as significant. This may be due to the slightly higher energy density of algae diesel compared to petrol-diesel which entitles an increase in the volume of injected fuel to maintain the same power output, thereby; increase in BSFC for algal diesel compared to petro-diesel was observed. The causal phenomenon also ratifying the high kinematic viscosity and density of fuels can cause a decrease in the fuel atomization and vaporization which leads to high BSFC[78]. Later, there was a low-temperature rise at 10% engine load, which affects a lean combustion mixture; as a result it can trigger even higher fuel consumption in low energy containing fuels, compared to fuels with higher heating values (Fig. 7).
However, the higher oxygen index of algal oil compared to diesel oil facilitates the complete combustion of the fuel blend which can certainly reduce the BSFC at higher loads, wherein there is a rise in temperature compared to low loads[79].

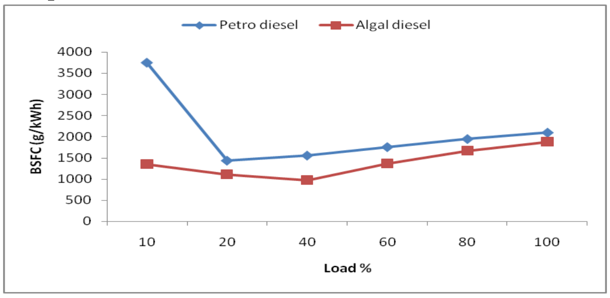

Figure 7. Brake Specific Fuel Consumption (BSFC) in Fuel blend of Algal diesel-petro-diesel at variable loads

3.8.1. Smoke Density (SD)

The brake power against smoke density of both algal diesel and diesel fuel with standard injection pressure displayed the lesser smoke density and reflected as significant to the engine system (Fig 8). It was evident in the previous reports as the parameter almost lies on the similar trend[80].

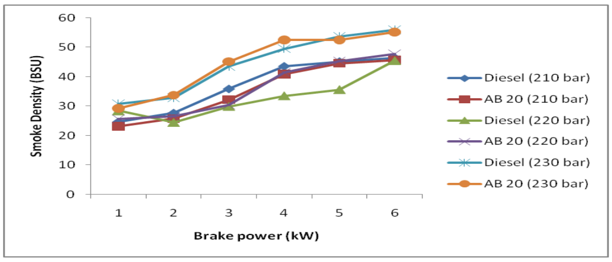

Figure 8. Brake power against smoke density in Fuel blend of Algal diesel-petro-diesel at variable injection pressure

3.8.2. Carbon Monoxide (CO)

The graph specifying the brake power against carbon monoxide has been observed and it was apparent that

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carbon monoxide emission increases as the load increases (Fig 9). When it is equated to the injection pressure, less carbon monoxide emission was noticed at the standard injection pressure than detained approach thus, the standard injection pressure was significant when it is associated with algae fuel and clean diesel fuel[81].

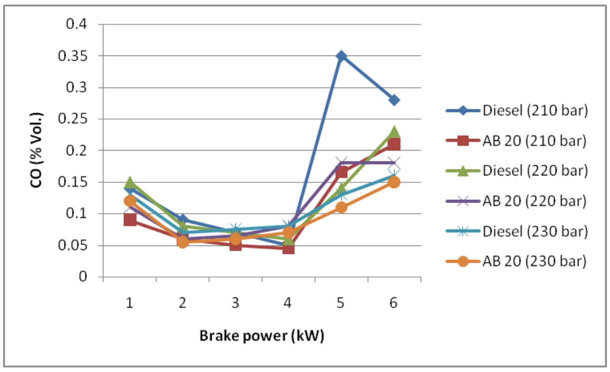
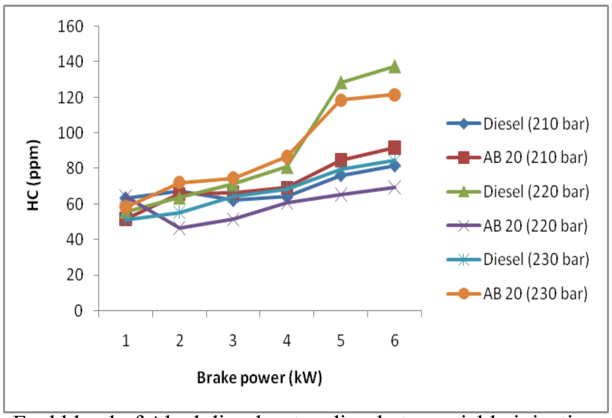


Figure 9. Brake power against carbon monoxide emission in Fuel blend of Algal diesel-petro-diesel at a variable injection pressure

3.8.3. Hydrocarbon (HC)

The considerable variation in the emission of hydrocarbon versus brake power was observed for the algae fuel and diesel fuel at various injection pressures (Fig 10). In the comparative approach, at the standard injection pressure of neat diesel fuel, the reduction in the amount of hydrocarbon was noticed. Specifically, AB20 with standard injection pressure showed the maximum reduction in the hydrocarbon emission[82].



Fuel blend of Algal diesel-petro-diesel at a variable injection pressure

3.8.4. Oxides of Nitrogen (NOx)

The graph obtained for brake power against oxides of nitrogen was critically analyzed for its expression

wherein, the oxides of nitrogen emission at the injection pressure of 210 bars was found to be average followed by varied injection pressures (Fig 11). The algae fuel at AB20 exhibited maximum reduction compared to that of all other factors[83].

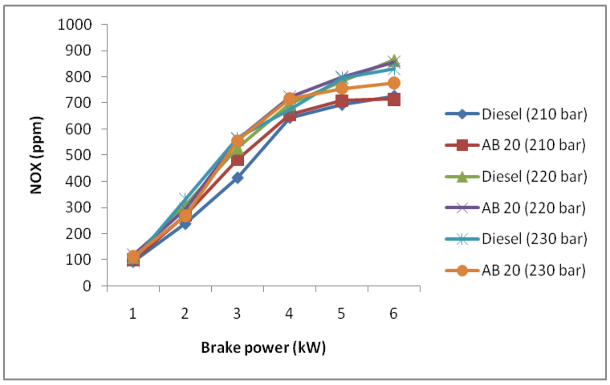


Figure 11. Brake power against oxides of nitrogen in Fuel blend of Algal diesel-petro-diesel at a variable injection pressure

3.8.5. Emission of CO_2 vs. Load

Initially, the deviance of the emission of CO2 with algal diesel blends at constant speeds of the engine was recorded. Further, the algal biodiesel blend exhibited lower CO2 emission compared to Petro-diesel. Theoretically, the emission of CO2 is due to the unfinished combustion particularly at low temperature and non-supply of oxygen into the combustion chamber.

In view of the fact that algal biodiesel blends contain a surplus amount of oxygen, which facilitates the combustion of fuel at a superior level and imparts the generation of higher temperature in the cylinder. This high temperature further makes possible the oxidation reaction for having conversion into CO2 towards the end[84]. The tendency of CO2 emission declined with the increase of loads in the engine (Fig 12).

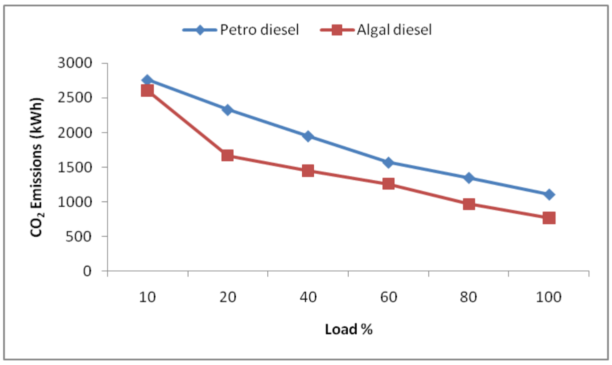


Figure 12. CO_2 Emissions (Kwh) Vs. Load (%) in Fuel blend of Algal diesel-petro-diesel

The capping and significant parameter is NOX when it comes to the interaction of the engine system with emission characteristics.

The differential approach in the emission of nitric oxide (NOX) with variable loads for both algal diesel and petro-diesel is represented in Figure 13.

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The NOX emission gradually increased with an increase in load at both algal diesel and petro-diesel blends respectively. Hypothetically, the emission of NOX is depending on the concentration of oxygen and higher temperatures in the combustion chamber. The emission of NOX was found to be higher at all the different loads, which may be due to a higher cetane number, which leads to enhanced combustion of the algal diesel. The increasing trend of temperature during the reaction of engine interaction will facilitate improved combustion of fuels, which ultimately increases the NOX formation. The NOX emission was considered as significant at algal diesel blend as compared to Petro-diesel at full load conditions[85, 86].

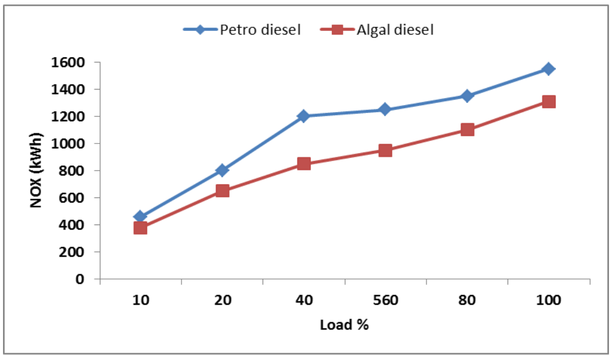

Figure 13. NOx Emissions (Kwh) Vs. Load (%) in Fuel blend of Algal diesel-petro-diesel

4. DISCUSSION

The only potential sources of alternative renewable fuel in the future are Microalgae which are available even in diversified ecological conditions. The microalgae are very minute aquatic organisms that transform sunlight into dynamic energy and hence these algal communities will have a stockpile of energy in the form of natural oils called 'Algae Fatty Acid Methyl ester' (AFME). Under reliable conditions, algae can further construct a lot of oil stack which can be converted later into biofuels. In addition, algae need carbon dioxide to grow and that is commendable for the environment, where it takes CO2 out of the atmosphere, establishing it an essentially carbon-neutral fuel source[87].

4.1. Algae Wild biomass to Biodiesel

Consequently, the algae are deliberated to be as the wildest rising primitive plant and theoretically, authenticated that their functional properties are effectual to produce a significant amount of oil as compared to other oil yielding crop plants. However, the ratio with respect to energy efficiency and carbon along with water footprint for algae-based biofuels are evaluated as the potential fuel sources that can replace the petroleum diesel. The algal lipids would be a superlative feedstock for generating transportation fuels with high energy density such as biodiesel, green jet fuel, and green gasoline, etc. This is in view of the fact that algae are not inclusive with food products, agricultural land and it exhibits the extreme ability to sequester large quantities of carbon dioxide in the environment. In addition, the practical analysis indicated that biodiesel is more focused on its power output due to higher oxygen content over the petro-diesel[88].

Hypothetically, multifarious fatty acids of different stretches esterified with alcohol, reliably methanol finally constitutes a Biodiesel. The theory reveals that the algae oil consisting of high free fatty acid content will be converted into Biodiesel by employing two phase chemical reactions *i.e.,* pre-esterification and transesterification processes. The biomass of microalgae is compelled by the higher growth rates and the lipid content of several species of algae is also superior when compared to other conventional plant crops. The competency of algal biomass is materialized as a valid biofuel feedstock which is directly proportional to the degree of saturation of its fatty acids validated with iodine value, oxidation stability, cetane number, etc. This has been categorically justified through its physical properties comprising viscosity, density, heating value, and melting temperature, etc.[89].

4.2. Engine performance with Algal Biodiesel

The parametric evaluation on performance and exhaust emissions of the experimental diesel engine fueled with blends of algal diesel and diesel fuels were remarkably deliberated. Prior to this, the analysis on fatty acid derived from microalgae, S. maxima showed fuel properties which were exceedingly significant and subsidized by fatty acid composition. In addition, the physico-chemical properties of biodiesel blends AB10 and AB20 were found to be close to diesel fuel. Subsequently, the heating value for each unit mass of algal diesel was found to be substantially more constructive than that of gasoline fuel. Therefore, the variation in the volumetric energy density of algal diesel compared to petro-diesel displayed lessening the difference of energy density on per unit volume basis respectively. The reduced difference in energy density was evident in the power and torque outputs generated by petro-diesel and algal diesel. In comparison, the algae biodiesel fuels had considerable power outputs as compared to petro-diesel that was also much closer to the expected power production based on the difference in volumetric energy density (kJ cm^{-3}). Eventually, the power produced by each fuel is directly interrelated to the volumetric energy density of the fuel[90, 91].
The torque output was observed for algal diesel wherein, analogous tendency coupled with most energy dense fuels attaining the maximum torque output similarly, the least energy-dense fuels generating the minimum amount of torque output. With this capacious background, the effectiveness of BSFC of algal diesel was correlated and was found to be considerably better

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than that of petro-diesel. On a serious note, the BSFC curve for algal biodiesel fuel was similarly shaped and no clear difference is evident in blends of biodiesel fuel studied [92,93].

In particular, the evaluation of brake specific fuel consumption is a crucial tool in assessing the consumption of fuel for every power output which is justified in the present study, where the power output of biodiesel was compared to petro-fuel. Besides, the higher oxygen content of algal diesel relating to fossil fuels is immensely accountable which may further contribute to significant energy density with well-balanced BSFC[94, 95, 96].

4.3. Emission characteristics of Algal Biodiesel

The imperative and vital aspect of using algal diesel as a supplement with petro-diesel is enhanced performance with improved characteristic features. Although the algal diesel was shown to reduce a number of emissions, including CO and hydrocarbons (HC) with unfinished combustion, the blending proportion of both algal diesel and petrol-diesel showed significant performance on most of the parameters. In general, it has been also noticed that algal diesel is attributed with substantial leading hold on all emission parameters. The obtained data on emission characteristics were critically analysed for both algal diesel and petrol-diesel covering CO_2, CO, and O_2 in percentage of total gas and HC and NOx as parts per million (ppm) respectively[97,98]. The increase in emission of CO_2 for algal diesel in relation to petroleum-diesel indicating improved combustion due to the presence of oxygen content in biodiesel has been substantiated. Besides, the CO emission was considerably reduced in the algal diesel compared to petro-diesel. Besides, the similar trend was also observed in Hydrocarbon emissions which were significantly higher in algal diesel fuel compared to petro-diesel. Subsequently, the convincing factor on the emission of NOx in algae biodiesel was noticeably lower than petro-diesel[99,100]. As a whole, the emission results are in agreement with the other studies on the potential of algal fuel technology. One such example is ‘Commercialization potential of microalgae for biofuels production’ where three crucial steps to the success of algal biofuel are listed: selection of the most desirable species, development of low cost production technology and production and marketing of other products derived from algae. Since these steps are being addressed, these authors also predict that, the algal biofuel will become commercially available in the near future [101].

5. CONCLUSION

The data obtained from the present investigation showed that biodiesel derived from wild stuff of algal biomass performed better on all the parameters. The approach of collecting the algal biomass directly in its natural ecosystem can be the most competent biofuel resources producing sustainable biodiesel as a substitute to the petroleum diesel. The production of algal biodiesel is found to be very cost-effective compared to the biodiesel produced from other plant oils. The characteristics of algal diesel were very much closer to petro-diesel when it is subjected for ASTM validation. Therefore, the algal diesel was able to exhibit similar potential of engine power and torque when compared to petro-diesel and the well-balanced approach in BSFC and BTE which was found to be significantly superior. The well-finished Hydrocarbon during combustion process and reduction of CO emissions was observed in algal diesel which may possibly trigger the optimized performance with respect to energy output. The reduction in NOx emissions in algal biodiesel than petro-diesel was recorded. Further, the findings of the present investigations validate that, microalga producing biodiesel explicitly showed analogous properties relating to engine parameters. In conclusion, the dynamic exploration of microalgae oils from its natural habitation can be a potential resource for biodiesel production which practically requires expansions in large scale cultivation, optimized processing followed by complete recovery of oils to achieve the sustainable biodiesel production.

Therefore, the results of the current study electrifies the equations on efficient biodiesel production from wild biomass of algae which is a preferential and well-organized approach as it is the most potential feedstock source that belongs to the non-edible oil category. Finally, the data of experimental investigations on the overall performance of the diesel engine test rig in tandem with all the specification fuelled by neat algae fuel (AB20) and diesel fuel was analysed with various injection pressure such as 210 bar, 220 bar, and 230 bar respectively, hence, the following conclusions are convoluted.

- ✓ The significant approach of brake thermal factor in AB20 blending at 210 bar compared to petro-fuel was noticed.
- ✓ The lesser smoke density was recorded with standard injunction pressure of algal fuel as compared to petro-fuel.
- ✓ The algal fuel (AB20) showed the maximum reduction of Carbon dioxide followed by diesel fuel.
- ✓ The maximum reduction of hydrocarbon emission with standard injunction pressure at AB20 was observed
- ✓ The algal biodiesel (AB20) exhibited considerable reduction of oxides of nitrogen in parallel with neat diesel at an injunction pressure of 210 bar compared to all other parameters.
- ✓ On the whole, AB20 blend displayed reduction in the emission of HC and CO gases up to 20 and 25%, respectively with a marginal difference in

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NOx up to 10–15% due to unsaturation moiety factor.

- ✓ The minimum exhaust emissions of pollutant gases were noticed for AB20 blending at 210 bar that adjacently followed the standard diesel. However, the significant results in all the parametric analysis at AB20 blending ratio which appeared to be cost effective, eco-friendly and technologically feasible.

Therefore, based on the generated results, it can be substantiated that the algae biodiesel derived from wild biomass of Spirulina maxima can be acclaimed as an alternative & prospective bio-fuel in the existing diesel engine system. The variation in the injection pressures particularly @ 210 bars displays a very significant change in the engine performance along with emission characteristics at AB20 blending fractions as compared to petro-fuel.

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Conflict of interest

I declare that there is no a conflict of interest with any person, institute, company, etc.

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