COMPARITIVE ANALYSIS OF BIODIESEL PRODUCED FROM ALGAE AND CONVENTIONAL DIESEL FUEL

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Abstract - *The increasing industrialization and increasing number of vehicles and engines are leading to a growing concern over the depletion of fossil fuels for biofuel production. This has led to a growing interest in renewable fuel sources like biofuels, which offer several advantages such as reduced greenhouse gas emissions, improved air quality, and enhanced energy security. However, the use of food-producing plants for biofuel production may disrupt food supplies and should not be the primary focus. Biofuels, including solid biomass, liquid fuels, and various biogases, are gaining attention due to increased energy security and fluctuations in oil prices. Algae, particularly microalgae, are particularly promising for biodiesel production due to their high lipid production capabilities. The project aims to develop and optimize a sustainable and cost-effective process for biofuel production from algae, covering cultivation, harvesting, lipid extraction, and biodiesel production. The nutritional quality of microalgae depends on the culture medium used. The outcomes of this project could contribute to the establishment of a sustainable and cost-effective process for biofuel production from algae, offering a viable alternative to conventional fossil fuels and fostering a more sustainable and environmentally friendly energy future.*

Key Words: Renewable Resources, Biodiesel Production, Algae, Transesterification, Chlorella sp., Biofuel

1. INTRODUCTION

The transportation sector's CO_2 emissions contribute to environmental pollution and global warming. With the cost of crude oil rising due to diminishing supply, the production of alternative fuels is crucial in the coming decade. Fossil fuels are unsustainable, leading to increased CO_2 levels and greenhouse gas accumulation. To ensure a clean environment and sustainability, there is a pressing need to produce renewable and environmentally friendly fuels. Biodiesel, derived from natural sources like vegetable oils, animal fats, and algae, is the most widely used biofuel due to its environmental advantages, including biodegradability and clean burning. Algae species are the primary source of biofuel production worldwide, offering numerous advantages over traditional feedstock sources like crops and waste materials. They can thrive in various environments, making them a more sustainable and efficient source of feedstock. The most widely used chemical process for this conversion is transesterification, which involves using a catalyst and alcohol to convert extracted lipids into biofuels. Algae can effectively remove toxic components from water, making them valuable contributors to wastewater treatment efforts. The project aims to compare the feasibility and efficiency of producing biodiesel from three different types of algae by conducting experiments and analyses.

1.1 PROBLEM IDENTIFICATION

- Fossil fuels contribute to climate change and environmental degradation.
- Fossil fuels are finite resources that will eventually run out.
- Hazardous emission from fossil fuels can lead to respiratory diseases.
- Extraction, transportation, and refining of fossil fuels are expensive.
- Fossil fuels pose safety risks.
- Air pollution.
- Water pollution.

2. LITERATURE REVIEW

- In 2017, a journal article by Suliman Khan, Rabeea Siddique, Wasim Sajjad, Ghulam Nabi, Khizar Mian Hayat, Pengfei Duan, and Lunguang Yao explored the potential of algae as biofuel producers, highlighting the need to avoid competing with food production and the potential of genetic technology.

- In 2023, Raviprajapati and Baraiya published a journal discussing the production of biodiesel from natural algae, a promising alternative fuel with similar physical and chemical properties to petroleum-based diesel, demonstrating its potential for sustainable development. Table 2.1 compares algal biodiesel with the Indian standards for diesel fuel.

- Hariram Venkatesan, Godwin John J., and Seralathan Sivamani's study evaluates the combustion and emission characteristics of algal and cotton seed biodiesel as alternative fuels for compression ignition engines, comparing them with mineral diesel. Table 2.2 presents a comparison between trans esterified biodiesel and ASTM biodiesel.

- Chee Loong Teo, Haryati Jamaluddin, Nur Azimah Mohd Zain, and Ani Idris published a study on biodiesel production using lipase-catalyzed transesterification of microalgae lipids from Tetraselmis sp. The study found that the lipase-catalyzed method yielded seven times more biodiesel than the alkaline-based method. Table 2.3 displays the variances in parameters between the Guillard and Walne culture media.

Table -2.1: Comparison of algal biodiesel and Indian standards of diesel.

Parameters	**Algal biodiesel**	**Indian standard**
Density	0.83gm/ml	0.73gm/ml
Flash point	98°C	120°C
Fire point	125°C	150°C
Viscosity	2.64 cSt	3.6 to 5.0 cSt
Smoke point	40°C	45-55°C
Specific gravity	0.84	0.88

Table -2.2: Comparison of trans esterified biodiesel and ASTM biodiesel.

SL NO.	PROPERTIES	D	AO	ABD	CSO	CBD	ASTM D975	ASTM D6751
1	Density at 15°C (kg/m^3)	850	892	865	910	885	-	860-900
2	Kinematic viscosity at 40°c (mm^2/s)	2.6	34	4	28	4.3	1.9-4.1	3.5-5.0
3	Calorific value (kJ/kg)	44800	39152	41750	36800	37500	44000	-
4	Cetane number	46	36	52	38	53	40-42	47-51
5	Flash point(°C)	64	72	114	49	150	52-54	101-130
6	Cloud point(oC)	-2	7	1	-	-3	-	-3-12
7	Pour point(°C)	-5	-10	-3	-	-8	-	-15-10
8	Ash point (%)	0.01	-	0.0192	-	0.013	>0.013	0-0.020
9	Carbon residue (%)	0.17	0.008	-	-	0.0112	>0.35	-
10	Oxygen content	-	8	10	10	12	-	2.5-12

Table -2.3: Difference in parameters of Guillard and Walne culture media.

PARAMETERS	GUILLARD	WALNE	REFERENCE
Ph.	8,31	8,17	7,2-8,5*
DO	2,96	2,96	2,00-4,00**
Temperature	30,20	30,53	25-31***
Salinity	28,75	28,50	17-30****

*Anderson (2005); Amsler (2008)
** Anderson (2005)
***Cahyaningsih (2006); Amsler (2008)
**** Cahyaningsih (2006); Kinoyo (2010)

3. METHODOLOGY

Algae can be produced using a wide variety of methods, ranging from closely-controlled laboratory methods to less predictable methods in outdoor tanks. The terminology used to describe the type of algal culture include:

Indoor/Outdoor:

Indoor culture allows control over illumination, temperature, nutrient level, contamination with predators and competing algae, whereas outdoor algal systems make it very difficult to grow specific algal cultures for extended periods

Open/Closed:

Open cultures such as uncovered ponds and tanks (both indoors or outdoors) are more readily contaminated than closed culture vessels such as tubes, flasks, carboys, bags, etc.

Axenic:

Axenic cultures are free of any foreign organisms such as bacteria and require a strict sterilization of all glassware, culture media and vessels to avoid contamination.

Batch culture:

The batch culture consists of a single inoculation of cells into a container of fertilized seawater followed by a growing period of several days and finally harvesting when the algal population reaches its maximum or near-maximum density.

Continuous culture:

The continuous culture method, (i.e. a culture in which a suply of fertilized seawater is continuously pumped into a growth chamber and the excess culture is simultaneously washed out), permits the maintenance of cultures very close to the maximum growth rate.

3.1 SELECTION OF ALGAE

Algae, particularly marine microalgae like Tetraselmis sp. and Nannochloropsis sp., are increasingly recognized as valuable sources for biofuel production due to their oil content, rapid growth rate, and safety. Algae can convert oil into fuels like kerosene oil and biodiesel through transesterification, making diesel production economical and straightforward. They are also known for their non-competitive, fast-growing nature, making them ideal for biodiesel production. Algae can thrive in saltwater environments, reducing freshwater strain and utilizing CO_2 as a primary carbon source. They can also be cultivated using wastewater or nutrient-rich water sources, reducing fertilizer use and pollution. Algae are categorized into seven groups, with green algae being particularly well-known for their use in biodiesel production.

CHLORELLA SP.:

Chlorella, a versatile microalga, is a promising biofuel source due to its high lipid content, rapid growth, and adaptability to various environmental conditions. Its fatty acid profile is well-suited for biodiesel production, and Chlorella sp. PG96 is a promising candidate due to its growth properties and capacity to accumulate high lipid levels. Chlorella requires less water, land, and fertilizer than traditional biofuel crops like corn and soybeans, making it a more sustainable and environmentally friendly choice. Its lipid content of up to 50% by weight makes it an efficient biofuel source.

The Central Marine Fisheries Research Institute (CMFRI) in Kochi provided samples of Chlorella sp.

3.2 DETERMINATION OF MEDIUM

The choice of growth medium is crucial for algae cultivation for biofuel production. Common media include Walne medium and Guillard's F/2 medium, which provide necessary nutrition and conditions for microalgae growth and multiplication. F/2 medium has gained popularity over Walne medium due to its nutrient-limiting properties and other advantages. It is essential to use appropriate media to ensure good growth and nutrition for the algae being produced. F/2 medium is a popular enriched seawater medium for coastal marine algae, particularly diatoms, with a halved concentration. It offers a more concentrated environment for algae growth, leading to higher lipid content in cells due to lower nutrient concentration. F/2 medium is more stable and less susceptible to contamination, resulting in a more consistent and higher yield of the final product. It is also more cost-effective to prepare, reducing overall production costs of biofuels derived from algae cultivated in this medium. It also allows for a higher density of algal cells, leading to greater yield per unit area. Walne medium requires more space for cultivation due to lower cell densities.

3.3 MEDIUM PREPARATION

The table 3.1 lists the quantities of chemicals required to prepare 1 liter of medium.

Mix each of the chemicals into approximately 750 ml of dH2O, ensuring thorough mixing between additions to fully dissolve. Once all chemicals have been added, make the solution up to 1 L. Refer to table 3.2 for the specific quantities of chemicals needed.

Mix both chemicals with 1 liter of dH2O and autoclave for dissolution. Afterward, store the solution in a dark place. The amounts of chemicals needed to prepare 1 liter of the solution are specified in table 3.3.

To prepare 1 litter of f2 Medium;

- Add each stock solutions in the Standard quantities to 1 L seawater
- Dispense to flasks and autoclave at 121°C (15 psi, 20 mints). Must be sterilized separately from seawater to prevent precipitation.
- Dilute original phosphate stock with dH2O such that 1 mL added to 75 mL of sterile medium will give the

required concentration of phosphate (11 mg L-1) in the medium.

- Autoclave dilute phosphate stock at 121°C (15 psi, 20 mints).
- After cooling, dispense aseptically with sterilized automatic dispenser.

Table -3.1: Lists the quantities of chemicals required to prepare 1 liter of medium.

SL NO.	STOCK SOLUTIONS	CONCENTRATION: gL^{-1} DEIONISED WATER (dH2O)	VOLUME FOR STANDARD MEDIUM	VOLUME FOR CONCENTRATED NUTRIENT STOCK
1	$NaNO_3$	150 g	0.5 mL	5.0 mL
2	$Na_2SiO_3.5H_2O$	22.7 g	0.5 mL	5.0 mL
3	$NaH_2PO_4.2H_2O$	11.3 g		5.0 mL
4	$Na_2EDTA.2H_2O$	30.0 g		
5	Trace metals solution	see recipe below	0.5 mL	5.0 mL
6	Fe citrate solution	see recipe below	0.5 mL	5.0 mL
7	Vitamins solution	see recipe below	0.5 mL	5.0 mL

Table -3.2: Quantities of chemicals required for preparing 1 litter of trace metal solution

CONSTITUENT	QUANTITY
$CuSO_4.5H_2O$	19.6 mg
$ZnSO_4.7H_2O$	44.0 mg
$CoCl_2.6H_2O$	22.0 mg
$MnCl_2.4H_2O$	360.0 mg
$Na_2MoO_4.2H_2O$	12.6 mg

Table -3.3: Quantities of chemicals required for preparing 1 litter of ferric citrate solution

CONSTITUENT	CONCENTRATION: mg L-1 DEIONISED WATER (dH2O)	WORKING STOCK QUANTITY
Vitamin B12	100 mg	1.0 mL
Biotin	100 mg	1.0 mL
Thiamine HCl	add reagent directly to stock	20.0 mg

The experiment involved collecting seawater from the nearest sea, filtering it with cotton to remove sand and dust particles, and storing it in a Duran bottle for sterilization in an autoclave apparatus, a crucial step in ensuring seawater sterilization.

3.4 AUTOCLAVE APPARATUS

Autoclaves are a reliable method for disinfecting and sterilizing medical instruments and labware using a combination of steam, pressure, and time. They eliminate microorganisms and spores, decontaminate biological waste, and sterilize medical instruments and lab ware. Autoclaves are highly recommended for rendering regulated medical waste inactive before disposal.

The autoclave uses moist heat sterilization to eliminate various microorganisms, including bacteria, viruses, and heat-resistant endospores. By producing saturated steam under pressure, it heats instruments to temperatures surpassing the boiling point of water, enhancing the sterilization temperature. The effectiveness of steam sterilization stems from the steam's moisture, which coagulates proteins that microbes rely on, rendering them inactive and ultimately leading to their demise.

In this study, the department of Biotechnology at Calicut University provided the necessary autoclave setup. The autoclave apparatus is depicted in figure 3.1.

Figure -3.1: ***Autoclave apparatus.***

3.5 GROWING OF ALGAE SEED

The cultivation of algae seeds in F/2 medium is crucial for achieving high lipid yields for biofuel production. The process involves inoculating the seeds into sterile medium, sealing the bioreactor, and maintaining a controlled environment. The growth phase begins, with gradual introduction of nutrients to maintain low nutrient concentration. As lipid accumulation begins due to nutrient limitation, cell growth slows down, marking the stationary phase. This phase is significant for lipid accumulation, as algae cells store lipids as an energy source during nutrient scarcity. **Figure 3.2 illustrates the development of algae in F/2 medium.**

The botany department at Calicut University, along with the Chemistry departments at both Calicut University and the Institute of Engineering and Technology, provide all the necessary setup for cultivating the medium and growing algae.

Figure -3.2: Algae developed in F/2 medium.

3.6 TANK PREPARATIOIN AND LARGE SCALE CULTIVATION

The old refrigerator's container is used for open cultivation of algae for biodiesel production. The tanks are cleaned and sun-dried to ensure quality growth. After being sealed with M-seal, they are disinfected with 70% methanol to prevent contamination. After a 24-hour period, one-fourth of the tank is filled with water, and the algae developed in F/2 medium is introduced. Daily checks and water levels are maintained, and the growth of algae is monitored. The tanks will turn pale green within 30 to 45 days, and the color will turn dark green (Figure 3.3), indicating the optimal time to harvest the algae. Regular monitoring and top-ups are necessary to ensure the highest quality algae.

3.7 HARVESTING OF ALGAE

Algae harvesting from open tanks requires careful separation of algae cells from the culture medium to minimize biomass loss. Here are the steps involved in the algae harvesting process:

- Harvesting algae during stationary phase to maximize quality.
- Equipment should be sterilized before harvesting to prevent contamination.
- Pre-treatment: helps separate algae cells from culture medium.
- Centrifugation: is the most commonly used method for harvesting algae cells.
- Drying: removes moisture content from algae cells to store and transport.
- Store: dried algae cells in airtight containers in cool, dry place.

Figure -3.3: fully developed algae tank.

Alum is a chemical compound used in large-scale open cultivation to settle algae. It is a hydrated double sulfate salt of aluminum, with an astringent and acidic taste. Alum is odorless, colorless, and typically found in a white crystalline powder. It is highly soluble in water and is used as a coagulant in water treatment. When added to the algae tank, it causes the algae to settle down. Excess water is drained out, leaving the settled algae. The algae are collected, dried into a paste, and processed using a spray dryer to produce algae powder.

3.8 SPRAY DRYER EQUIPMENT

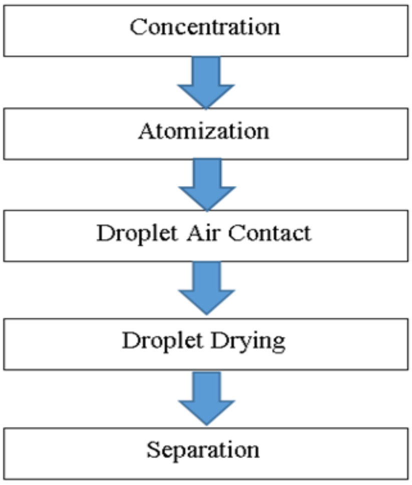
A spray dryer is a method for rapidly drying liquids or slurry using hot gas, especially for products like foods and medicines that are sensitive to heat. It separates solute and solvent to create solids through heat transfer, making it faster and simpler than other methods. High-pressure single-fluid and two-fluid nozzles are commonly used for drying. In pharmaceutical production, spray drying is crucial for producing Amorphous Solid Dispensation, which evenly disperses Active Pharmaceutical Ingredients into a polymer matrix, enhancing drug dispersion and facilitating medication distribution. The machine uses a feed pump, atomizer, air heating unit, air dispenser, and drying chamber to dry liquids. The atomizer spins at 3,000-50,000 RPM, atomizing the liquid into droplets and heating them up.

Figure -3.4: Spray dryer.

There are three fundamental steps involved in spray drying.

- Atomization of a liquid feed into fine droplets.
- Mixing of these spray droplets with a heated gas stream, allowing the liquid to evaporate and leave dried solids.
- Dried powder is separated from the gas stream and collected.

The flowchart provided illustrates the process involved in operating a spray dryer.



3.9 EXTRACTION OF ALGAEL OIL

Soxhlet extraction is an economical method for isolating bioactive compounds from natural sources. It involves distilling a dry sample in a thimble and transferring it to a flask with the desired solvent. This process ensures continuous extraction of solid matter, enhancing efficiency and reducing costs, and the extracted oil is used in the transesterification process to produce biodiesel.

SOXHLET EXTRACTION:
Soxhlet extraction is a chemical process used to extract bioactive compounds from natural sources. It involves dissolving a dry sample in a solvent and transferring it from one phase to another, with the solute having higher solubility in the second phase. Common extraction types include liquid/liquid, liquid/solid, and acid/base. The Soxhlet extractor is used to perform sample extraction by placing the sample on filter paper and assembling the device. A solvent is added to a reservoir flask and heated, mixing the soluble part with the solvent for extraction. The solvent is then siphoned back when it surpasses the maximum height of the siphon. This process is repeated with the flask to extract portions of the material each time, ensuring pure solvent use and concentration.

The algae powder is placed in an extraction thimble, and 300 mL of hexane is added to a 500-mL round bottom flask. The sample is extracted for 4-6 hours at 4-6 cycles/hour at 80-85 degrees Celsius. After extraction, a mixture of hexane and algal oil is obtained, which is then transferred to a roto-vapor apparatus to remove the hexane content.

3.10 SOXHLET APPARATUS

The Soxhlet extractor, invented by Franz von Soxhlet in 1879, is a crucial laboratory tool for extracting lipids from solid materials. It is particularly useful when a compound has limited solubility in a solvent and the impurity is insoluble. The extractor consists of a percolator for circulating the solvent, a thimble for retaining the solid material, and a siphon mechanism for emptying the condensed solvent. The source material is placed inside the thimble, which is then loaded into the main chamber. The solvent is added to a distillation flask, and the Soxhlet extractor is positioned on top of it, with a reflux condenser on top. This setup allows for efficient solvent recycling, allowing for the dissolution of larger quantities of material without constant monitoring or management. The solvent is gently heated in a reflux process, causing the vapor to rise up a distillation arm and reach the chamber containing the solid material. As the chamber nears fullness, the contents are emptied using a siphon, and the solvent is returned to the distillation flask. The solvent is eliminated using a rotary evaporator, yielding the extracted compound. The Kumagawa extractor features a specific design, with the thimble holder/chamber suspended inside the solvent flask above the boiling solvent, allowing for improved extraction of compounds with higher melting points.

The diagram 3.5 illustrates the setup of the Soxhlet apparatus, while diagram 3.6 depicts the schematic arrangement of the same apparatus.

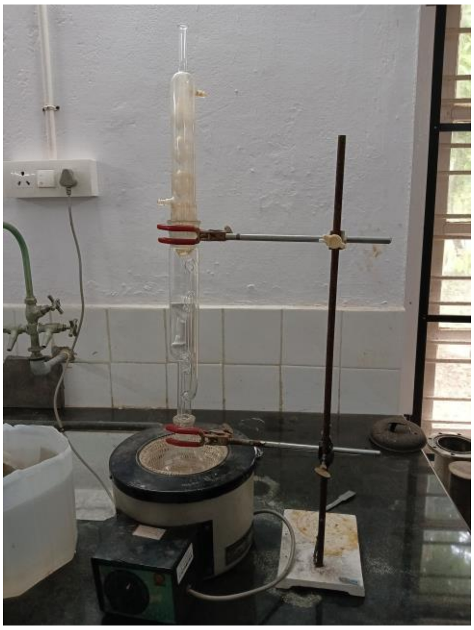


Figure -3.5: setup of the Soxhlet apparatus.

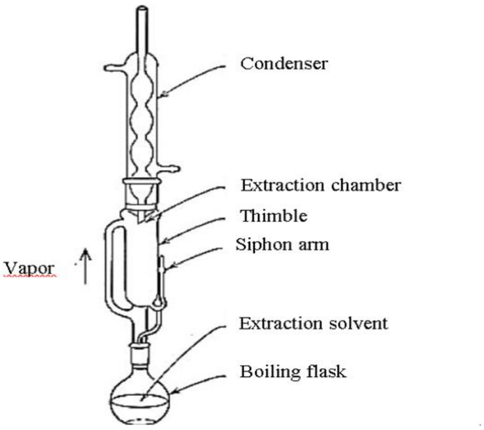


Figure -3.6: schematic arrangement of the soxhlet apparatus.

3.11 ROTO VAPOR

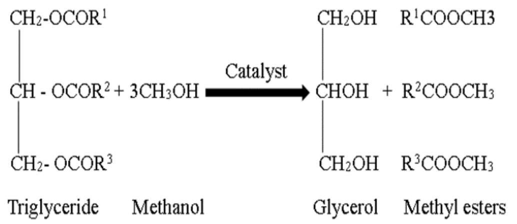
The rotary evaporator, also known as a rotavap, is a chemical laboratory device used to efficiently remove solvents from samples through evaporation. It works by lowering pressure, rotating the sample, and heating the solution. To use, ensure power is turned on at the top right of the stand. The steps for operating a rotary evaporator are as follows:

- To reduce water usage in experiments, use a water circulator with a water reservoir, as most evaporation processes are designed with water reservoirs.
- Before using an apparatus like a round-bottomed flask, ensure it is filled to over half its capacity with the solution needed for evaporation.
- The Keck clip is crucial for connecting the flask to the evaporator's bump trap, ensuring a steady connection and preventing foam or splashing solutions from overflowing. It's essential to keep the bump trap clean before any laboratory procedure to prevent contamination.
- The guide outlines using a joystick knob to lower a flask in water, ensuring it's not too close to the bottom and not in contact with water.
- The guide outlines using a joystick knob to lower a flask in water, ensuring it's not too close to the bottom and not in contact with water.
- Rotate the flask at moderate speed, accurately adjusting the rotation notch to one-third of the maximum rotation value.
- Close the stopcock by turning the evaporator perpendicular to the bleed valve, thereby stopping hissing and allowing pressure to gradually decrease.
- The solvent will gradually evaporate in the flask, with no specific duration, just allow it to gather.
- The sample should be kept at reduced pressure for a period to ensure the complete removal of any remaining solvent residue.
- To prevent evaporation, follow the steps in reverse.
- The compound you're searching for can be found in the residue accumulated in the flask, possibly with solvent traces, and can be left exposed for some time.

Figure -3.7: roto-vapor.

3.12 TRANSESTERIFICATION

Biodiesel, a biofuel derived from vegetable oils and animal fats, is produced through the conversion of long chain fatty acids. It is commonly used in compression ignition engines and is produced through transesterification, where oil components are converted into simple alkyl esters by reacting with short chain alcohols like methanol and ethanol. The efficiency of this process depends on the type and quantity of catalyst used, which can be homogeneous or heterogeneous based on its phase with the reactants. Transesterification is a cost-effective and efficient method for producing biodiesel, as it involves swapping the R group of an alcohol with the R' group of an ester. This process produces mono-alkyl esters, the primary components of biodiesel, and glycerol as a secondary product. Biodiesel produced through transesterification offers numerous benefits compared to traditional petroleum diesel, including reduced emissions, enhanced lubricity, and biodegradability. The process of converting oils through transesterification reaction can be depicted below,



For this experiment, we utilized KOH as the catalyst. We added 1.5 weight% of KOH to 5.92 parts methanol to 1-part oil ratio. The mixture was thoroughly stirred until the oil completely dissolved. Subsequently, the oil was added to the methanol and KOH mixture and stirred well again. The resulting mixture in the round bottom flask was then placed in a transesterification setup as depicted in figure 3.8 and heated to approximately 50-60 degrees Celsius for 4-5 hours. After heating, two distinct layers were observed as in figure 3.9. The upper layer comprised the methyl ester, which is the biodiesel, as its density is lower than that of the glycerol observed at the bottom of the round flask. The separation of the biodiesel and glycerol was achieved using a separating funnel.

Figure -3.9: Two distinct layers of methyl ester and glycerol.

Figure -3.8: transesterification setup.

4. RESULTS

In this experiment, we gained valuable insights into the process of converting algae into diesel. The production of biodiesel from algae proved to be both time-consuming and expensive, requiring a significant amount of delicate and costly equipment. The yield of diesel obtained was minimal, and the production process necessitated the consumption of a substantial amount of additional energy, including heat and electricity. In this study, we initially obtained 1.8kg of wet algae paste, which reduced to 810g of algae powder after drying. Through the soxhlet extraction process, only 430ml of oil was obtained from the algae powder, leading to a yield of just 260ml of biodiesel. Despite the limited quantity, we proceeded to conduct a load test on a single-cylinder 4-stroke diesel engine using a 20% blend of the biodiesel. The test results, including density, flash point, and fire point comparisons, are detailed below.

4.1 FLASH POINT

The flash point is the lowest temperature at which a liquid releases vapor in a test vessel, creating an ignitable mixture with the air near its surface. A lower flash point makes it easier to ignite a solvent. A liquid hydrocarbon's flash point indicates the temperature it needs to be heated to produce enough flammable vapour to ignite when exposed to a flame. Diesel fuels have a flashpoint ranging from 52°C to 93°C, with fuels below 60°C classified as flammable and those above 60°C as combustible. Biodiesel blended with 20% has a flash point of 53°C.

4.2 FIRE POINT

The fire point of a fuel is the minimum temperature at which a fuel vapor can sustain combustion for at least five seconds after being ignited by a standard-sized open flame. It is the precise temperature at which the vapors of a substance sustain combustion even after being ignited. The flash point and fire point are crucial in assessing the volatility and fire resistance of lubricants, as well as determining the necessary temperature conditions for transportation and storage. Lubricant manufacturers can use the flash point to identify potential contamination in their products. Diesel fuel's flash point ranges from 52 to 96°C, while a 20% blended biodiesel's flash point is around 68°C.

4.3 CLEVELAND APPARATUS

Figure -4.1: Cleveland apparatus

The Cleveland flash tester measures the flash and fire point of petroleum products by increasing temperature until flammable vapor ignites with a test flame. It determines the fire point, the temperature at which the test flame produces at least five seconds of ignition, and operates within a temperature range of 120 to 250 degrees Celsius.

4.4 DENSITY

Density is the mass of a substance per unit of volume, influenced by its atoms' mass, size, and arrangement. It is calculated by dividing the substance's mass by its volume. A relative density less than 1 indicates less density than a reference substance, while a higher density indicates denserness. When the relative density is exactly 1, the densities of two substances are equal, meaning equal volumes have the same mass. Diesel fuel typically has a density of 830-860 kg/m^3 at room temperature, while our 20% blended biodiesel has a density of 836.8 kg/m^3 at 32°C. Density is crucial in understanding the properties of materials and their potential applications.

We obtained the density information at the Indian Oil petrol pump located in Koottilangadi, Malappuram.

4.5 ENGINE PERFORMANCE

In a comprehensive study, it was found that the mechanical efficiency of an engine running on biodiesel is not significantly different from that of an engine running on normal diesel. The load test setup is clearly depicted in figure 4.2. Table 4.1 presents the readings and results of the load test conducted on a single cylinder 4-stroke diesel engine using normal diesel, while figure 4.3 shows the BP V/S TFC curve to find FP, figure 4.4 illustrates the BP V/S mechanical efficiency curve, figure 4.5 illustrates the BP V/S SFC curve, in figure 4.6 and 4.7 we can see the BP V/S Brake thermal efficiency and BP V/S Indicated thermal efficiency respectively.

Table 4.2 displays the readings and results of the load test on a single cylinder 4-stroke diesel engine using 20% blended biodiesel, and figure 4.8 demonstrates the BP V/S TFC curve to find FP. Additionally, figure 4.9 provides an explanation of the BP V/S mechanical efficiency curve, figure 4.10 gives the details of the curve BP V/S SFC, figure 4.11 and figure 4.12 shows the BP V/S Brake thermal efficiency and BP V/S Indicated thermal efficiency of 20% blended biodiesel respectively.

In Table 4.3, you can find the readings and results of the load test conducted on a single cylinder 4-stroke diesel engine using 15% blended biodiesel. Additionally, Figure 4.13 illustrates the BP V/S TFC curve to determine FP, while Figures 4.14 and 4.15 display the BP V/S mechanical efficiency curve and the BP V/S SFC curve and figure 4.16 and figure 4.17 shows the BP V/S Brake thermal efficiency and BP V/S Indicated thermal efficiency of 15% blended biodiesel, respectively.

Moving on to Table 4.4, it provides the readings and results of the load test on a single cylinder 4-stroke diesel engine using 10% blended biodiesel. Furthermore, Figure 4.18 depicts the BP V/S TFC curve for finding FP, and Figures 4.19 and 4.20 show the BP V/S mechanical efficiency curve and the BP V/S SFC curve and figure 4.21 and figure 4.22 shows the BP V/S Brake thermal efficiency and BP V/S Indicated thermal efficiency of using 10% blended biodiesel.

We conducted the load test on a single cylinder 4-stroke diesel engine and checked the flash point and fire point at the Thermal Engineering Lab at Calicut University Institute of Engineering and Technology.

4.6 LOAD TEST SETUP

The experimental configuration includes a single cylinder 4 stroke diesel engine, a top load system, a fuel tank, exhaust gas, and a manometer. The 4-stroke diesel engine with a single cylinder is being tested under load, boasting a maximum power output of 5HP. The brake drum has a radius of about 0.16 meters, the piston diameter is 87.5mm, stroke length is 110mm, brake drum diameter is 300mm, orifice diameter is 20mm, and the discharge coefficient is 0.62.. The supplied engine from Kirloskar Company is a self-governed type, single-cylinder, vertical, four-stroke, air-cooled CI engine. The engine is connected to a brake drum dynamometer, which functions as a loading device using a rope brake setup.

Figure -4.2: load test setup.

- Air Supply System

The engine cylinder's suction side is connected to an air tank, allowing atmospheric air to enter. A water manometer measures pressure drop across an intake pipe, calculating air volume.

- Fuel Supply System

The fuel system consists of a fuel tank, filter, pump, and injector, with fuel stored in an overhead tank. After filtration, it's directed to the pump via gravity and delivered to the injector, spraying it into the cylinder as a fine mist.

- Lubricating System

The engine part is supplied with lubricating oil to minimize friction between moving parts and dissipate the heat caused by friction. Once filtered, the lubricating oil is distributed to various moving parts of the engine from the lubricating pump.

- Loading System

The brake drum dynamometer is a power absorbing device used to test an engine's performance under load. It converts the crankshaft's rotational tendency into tangential force, measuring brake power (B.P). The rope drum dynamometer uses a rope wrapped around the engine's brake drum, with one end carrying a dead load and the other connected to a spring balance. The drum's rotation is always against the dead load's pull, allowing all power to be absorbed by friction. The brake drum is typically water-cooled to dissipate heat generated from absorbed power.

PRECAUTIONS:

- Fuel and lubricating oil are checked and if needed they are to be supplied.
- Cooling water inlet and outlet for engine jacket and brake drum should beopened.
- Engine should be started and stopped with no load.
- De-compression liver should be engaged before cranking.

WORKING:

The formula is used to calculate the maximum load that can be applied to the engine before starting it.

$$\mathrm{B.P} = \frac{2\pi NT}{60}$$

Torque, T

$$T = FR = (W_1 - S) \times g \times R$$
$$Maximum\ Load = (W_1 - S)\ Kg$$

Start the engine without load, with the fuel supply on and the decompression lever engaged. Record the time for fuel consumption and water manometer level difference. Apply initial load, record spring dial reading, and repeat until maximum load is reached. Stop the engine by cutting the fuel supply.

THEORY:

- Output Power or Brake Power

$$\mathrm{B.P} = \frac{2\pi NT}{60}\ KW$$

- Torque

$$T = FR = (W_1 - S) \times g \times R\ Nm$$

- Total Fuel Consumption

$$TFC = \frac{\mathrm{V} \times 3600 \times \rho \times \mathrm{d}}{1000 \times t_m}\ \ Kg/hr$$

- Specific Fuel Consumption

$$\mathrm{SFC} = \frac{TFC}{BP}$$

- Indicated Power

I.P = B.P + F.P

Where,

The Frictional Power (F.P) is derived from the characteristic plot (TFC Vs B.P).

- Mechanical efficiency

$$\eta_{ME} = \frac{BP}{IP} \times 100$$

- Brake thermal efficiency

$$\eta_{BT} = \frac{BP \times 3600}{TFC \times CV} \times 100$$

- Indicated thermal efficiency

$$\eta_{IT} = \frac{BP \times 3600}{TFC \times CV} \times 100$$

CALCULATIONS:

Table -4.1: Readings and results of the load test conducted on a single cylinder 4-stroke diesel engine using normal diesel.

SL NO		1	2	3	4	5	6
Load	(W_1) kg	0	2	4	6	8	10
	(S) kg	0	0.8	1.2	2.2	2.9	3.1
Torque, T	Nm	0	1.88	4.39	5.96	8.004	10.83
Speed, N	rpm	1500	1500	1500	1500	1500	1500
Time for 5cc fuel consumption	sec	39.65	28.5	25.91	24.28	23.58	22.06
BP	kw	0	0.29	0.68	0.93	1.25	1.7
TFC	Kg/hr	0.38	0.53	0.59	0.63	0.64	0.69
SFC	Kg/kwhr	-	1.82	0.86	0.67	0.512	0.405
IP	kw	1.4	1.69	2.08	2.33	2.65	3.1
η_m	%	0	17.15	32.69	39.91	47.16	54.38
η_{BT}	%	0	4.37	9.22	11.8	15.62	19.71
η_{IT}	%	29.47	25.5	28.2	29.58	33.12	35.94

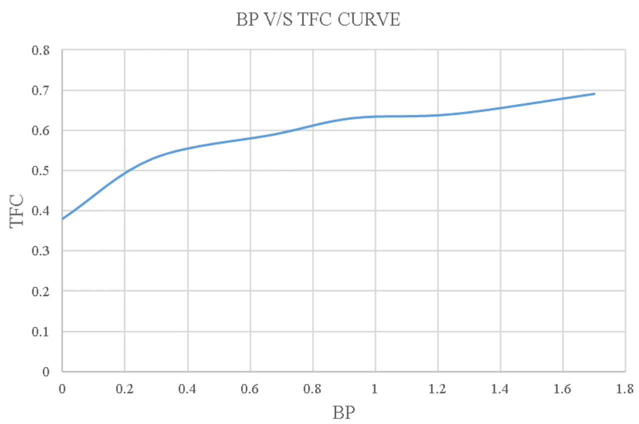


Figure -4.3: BP V/S TFC curve to find FP.

From this graph the value of FP is 1.4

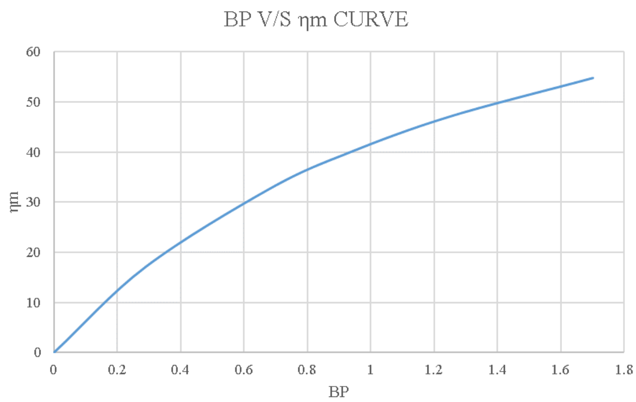


Figure -4.4: BP V/S mechanical efficiency curve.

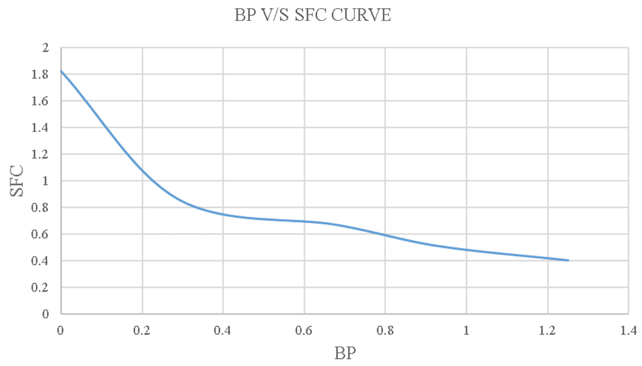


Figure -4.5: BP V/S SFC curve.

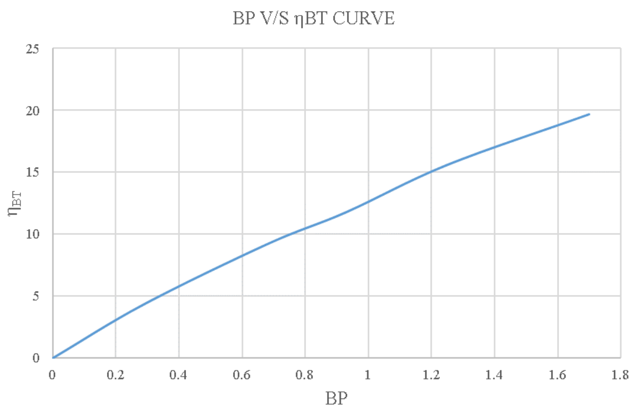


Figure -4.6: BP V/S Brake thermal efficiency.

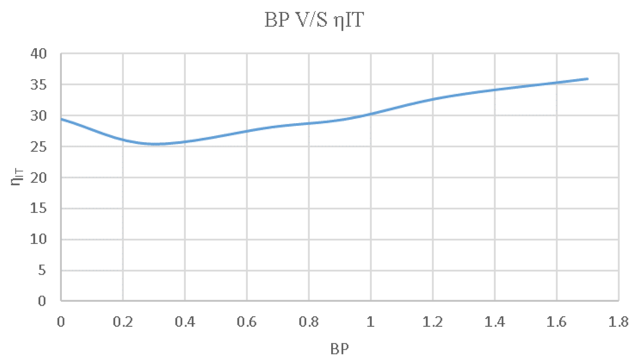


Figure -4.7: BP V/S Indicated thermal efficiency

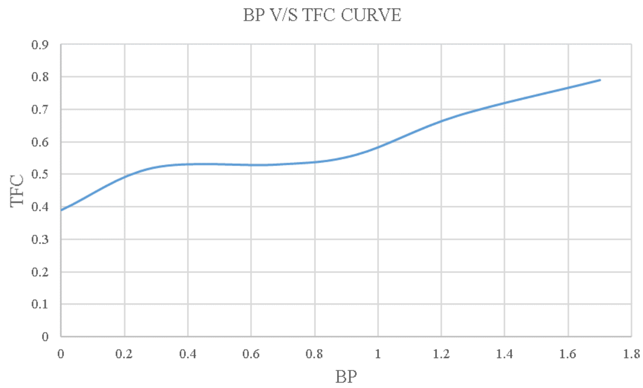


Figure -4.8: BP V/S TFC curve of the load test using 20% blended biodiesel.

From this graph the value of FP is 1.7

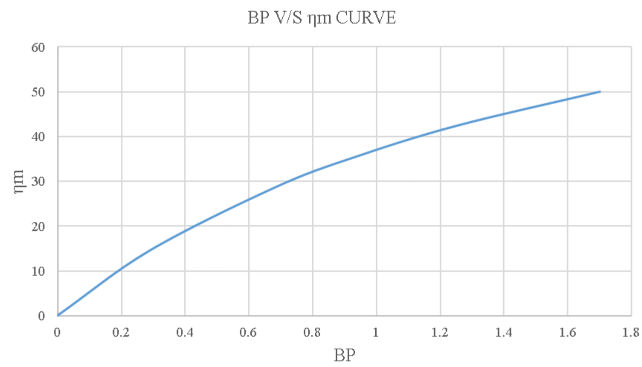


Figure -4.9: BP V/S ηm curve of the load test using 20% blended biodiesel.

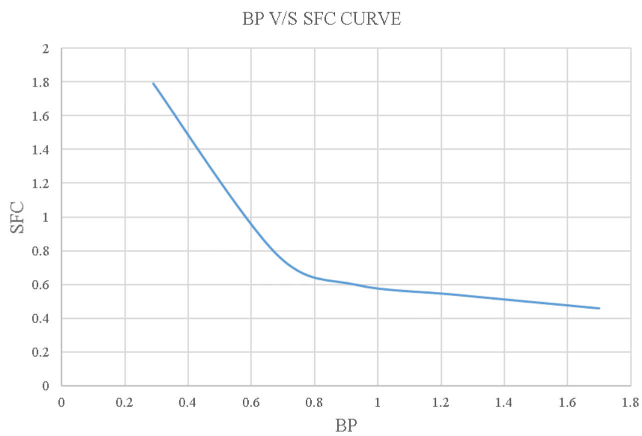


Figure -4.10: BP V/S SFC curve of the load test using 20% blended biodiesel.

Table -4.2: Readings and results of the load test on a single cylinder 4-stroke diesel engine using 20% blended biodiesel.							
SL NO		1	2	3	4	5	6
Load	kg	0	2	4	6	8	10
	kg	0	0.8	1.2	2.2	2.9	3.1
Torque	Nm	0	1.88	4.39	5.96	8.004	10.83
Speed	rpm	1500	1500	1500	1500	1500	1500
Time for 5cc fuel consumption	sec	38.38	29.03	28.20	26.94	22.06	18.93
BP	kw	0	0.29	0.68	0.93	1.25	1.7
TFC	Kg/hr	0.39	0.52	0.53	0.56	0.68	0.79
SFC	Kg/kwhr	-	1.79	0.78	0.60	0.54	0.46
IP	kw	1.7	1.99	2.38	2.63	2.95	3.4
η_m	%	0	14.57	28.57	35.36	42.37	50.00
η_{BT}	%	0	5.15	11.84	15.33	16.97	19.86
η_{IT}	%	40.24	35.33	41.45	43.35	40.05	39.73

Table -4.3: Readings and results of the load test on a single cylinder 4-stroke diesel engine using 15% blended biodiesel.							
SL NO		1	2	3	4	5	6
Load	kg	0	2	4	6	8	10
	kg	0	0.8	1.2	2.2	2.9	3.1
Torque	Nm	0	1.88	4.39	5.96	8.004	10.83
Speed	rpm	1500	1500	1500	1500	1500	1500
Time for 5cc fuel consumption	sec	39.65	28.5	25.91	24.28	23.58	22.06
BP	kw	0	0.29	0.68	0.93	1.25	1.7
TFC	Kg/hr	0.416	0.557	0.539	0.647	0.665	0.771
SFC	Kg/kwhr	-	1.92	0.793	0.696	0.532	0.454
IP	kw	1.4	1.69	2.08	2.33	2.65	3.1
η_m	%	0	17.15	32.69	39.91	47.16	54.83
η_{BT}	%	0	4.80	11.64	5.56	17.35	20.35
η_{IT}	%	31.06	28.01	35.62	33.24	36.78	37.11

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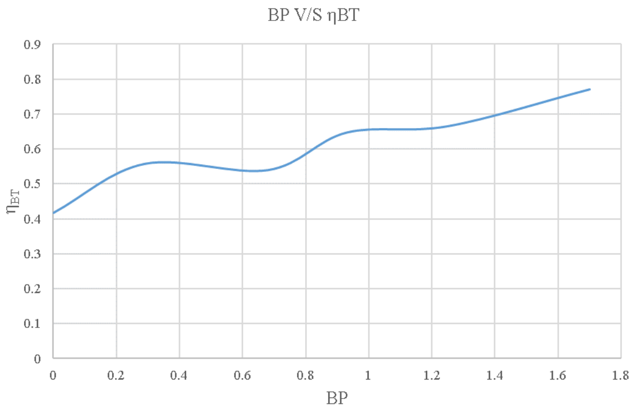

Figure -4.11: BP V/S ηBT curve of the load test using 20% blended biodiesel.

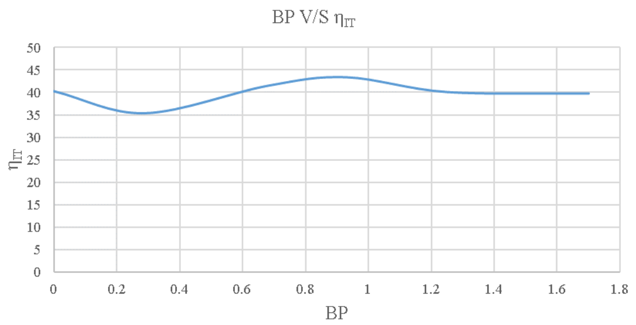

Figure -4.12: BP V/S ηIT curve of the load test using 20% blended biodiesel.

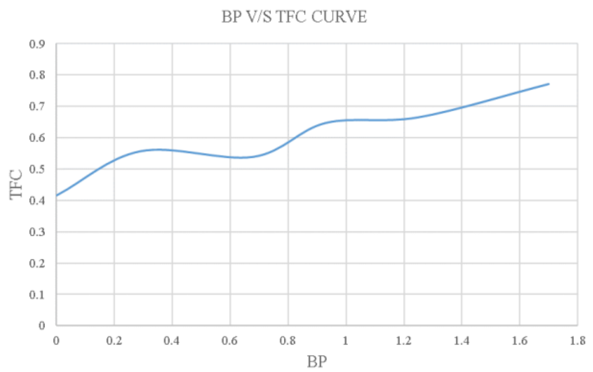

Figure -4.13: BP V/S TFC of the load test using15% blended biodiesel.

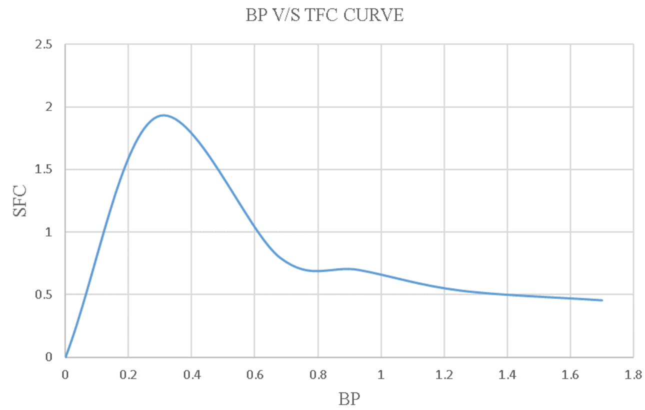

Figure -4.14: BP V/S SFC of the load test using15% blended biodiesel.

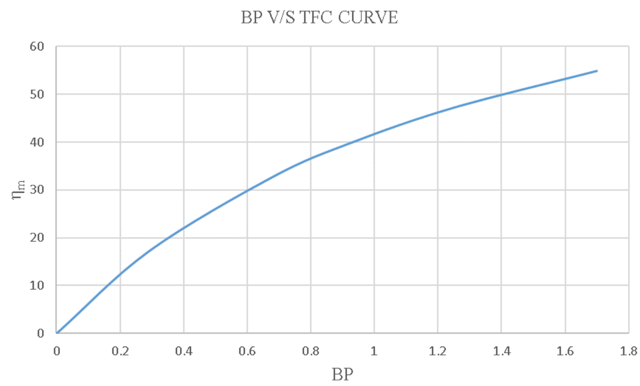

Figure -4.15: BP V/S ηm of the load test using15% blended biodiesel.

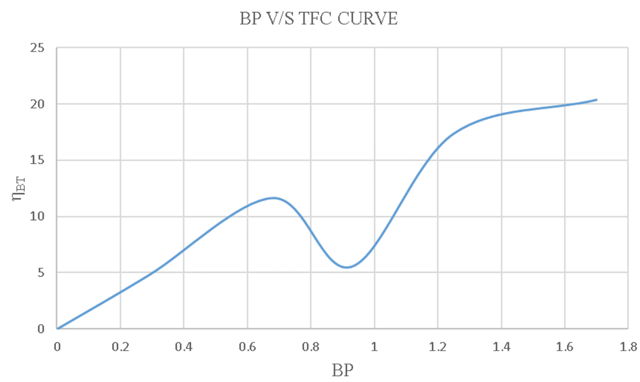

Figure -4.16: BP V/S ηBT of the load test using15% blended biodiesel.

Table -4.4: Readings and results of the load test on a single cylinder 4-stroke diesel engine using 10% blended biodiesel .

SL NO		1	2	3	4	5	6
Load	kg	0	2	4	6	8	10
	kg	0	0.8	1.2	2.2	2.9	3.1
Torque	Nm	0	1.88	4.39	5.96	8.004	10.83
Speed	rpm	1500	1500	1500	1500	1500	1500
Time for 5cc fuel consumption	sec	39.65	28.5	25.91	24.28	23.58	22.06
BP	kw	0	0.29	0.68	0.93	1.25	1.7
TFC	Kg/hr	0.399	0.465	0.547	0.562	0.680	0.715
SFC	Kg/kwhr	-	1.603	0.804	0.604	0.544	0.421
IP	kw	1.6	1.89	2.28	2.53	2.85	3.3
η_m	%	0	15.34	29.82	36.76	43.86	51.52
η_{BT}	%	0	5.76	11.48	15.28	16.97	21.95
η_{IT}	%	37.02	37.52	38.48	41.55	38.69	42.60

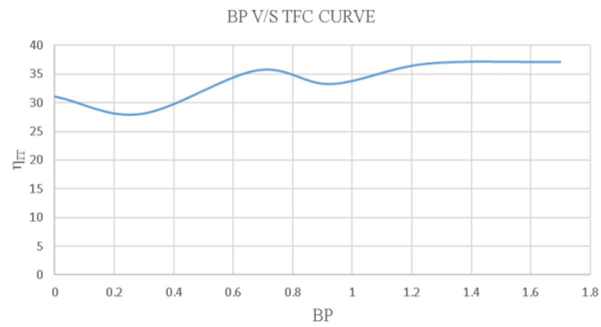

Figure -4.17: BP V/S ηIT of the load test using15% blended biodiesel.

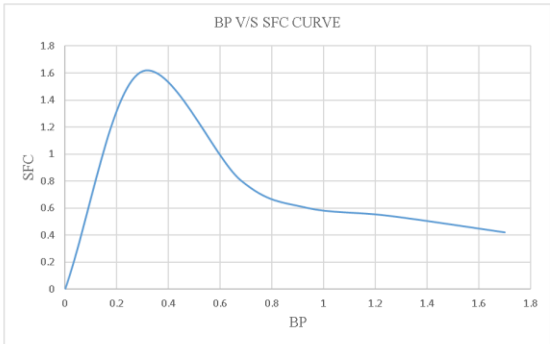

Figure -4.19: BP V/S SFC of the load test using10% blended biodiesel.

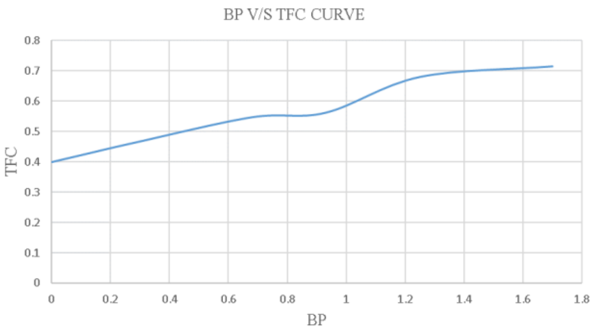

Figure -4.18: BP V/S TFC of the load test using10% blended biodiesel.

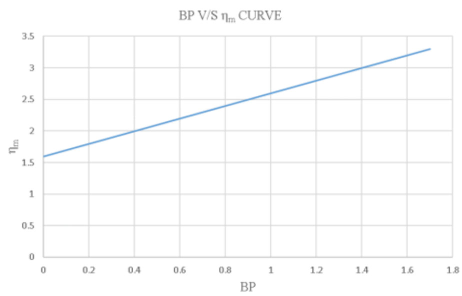

Figure -4.20: BP V/S ηm of the load test using10% blended biodiesel.

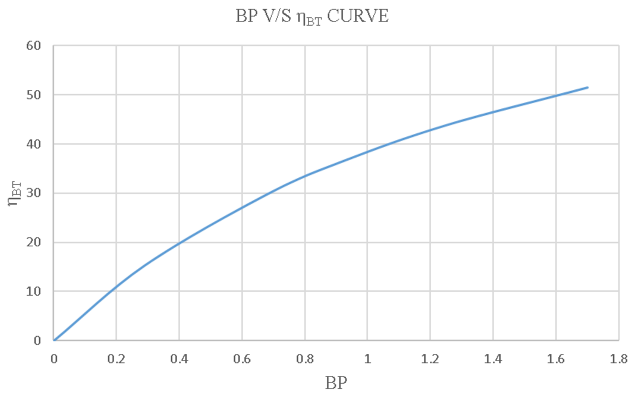

Figure -4.21: BP V/S ηBT of the load test using10% blended biodiesel.

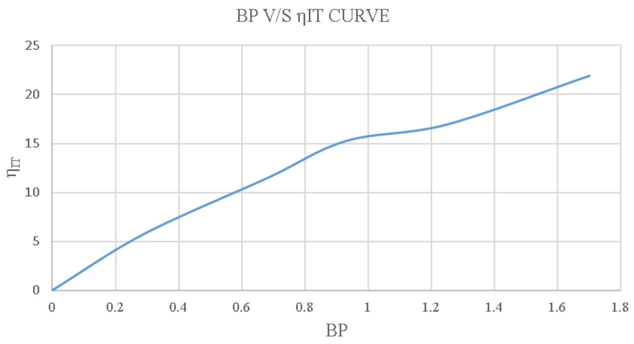

Figure -4.22: BP V/S ηIT of the load test using10% blended biodiesel.

4.7 COMPARISON

MECHANICAL EFFICIENCY:
The average mechanical efficiency of a 4-stroke diesel engine using regular diesel is 38.258%. When using a 20% blend, the efficiency drops to 34.174%, while a 15% blend results in an efficiency of 38.348% and a 10% blend yields an efficiency of 35.46%.

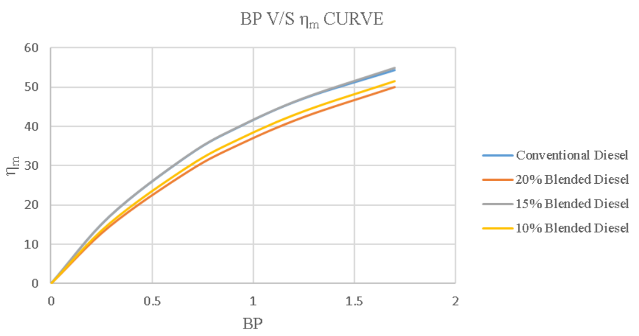

Figure -4.23: Comparison of ηm of conventional and blended diesel.

BRAKE THERMAL EFFICIENCY:
The brake thermal efficiency of a 4-stroke diesel engine with regular diesel is 12.144%. When using a 20% blend, the efficiency increases to 13.83%, while a 15% blend results in an efficiency of 11.94% and a 10% blend leads to an efficiency of 14.288%.

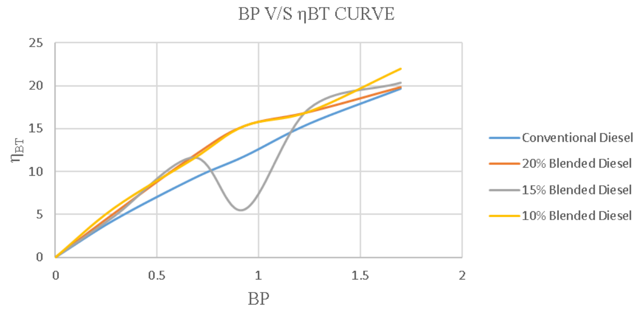

Figure -4.24: Comparison of ηBT of conventional and blended diesel.

INDICATED THERMAL EFFICIENCY:
The average indicated thermal efficiency of a 4-stroke diesel engine using regular diesel is 30.30%. However, when using a 20% blend, the efficiency increases to 40.025%. Similarly, the efficiency using a 15% blend is 33.64%, and when using a 10% blend, the efficiency is 39.31%. These findings demonstrate the impact of different fuel blends on the engine's performance.

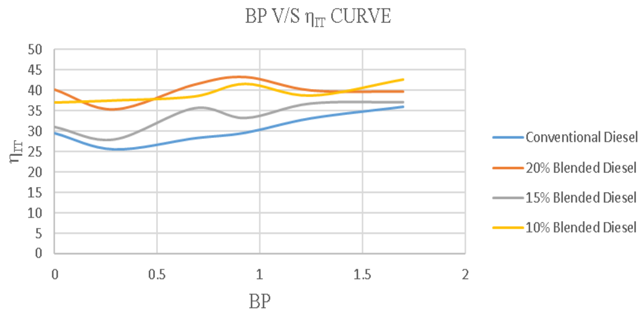

Figure -4.25: Comparison of ηIT of conventional and blended diesel.

5. CONCLUSION

During our experiment, we discovered that different types of algae can thrive in different conditions. While Nannochloropsis and Tetraselmis did not survive in the same conditions, Chlorella sp. did, so we will focus on further processing Chlorella sp. only. As a result, we were unable to observe the details of producing biodiesel from Nannochloropsis and Tetraselmis, as well as the properties and performance measures of biodiesel from these algae.
Based on the experiment conducted, it can be inferred that there are minimal variations in the efficiency and

parameters of the engine load test on a single cylinder 4-stroke diesel engine. The 4-stroke diesel engine's mechanical efficiency with regular diesel is 38.258%. However, when using a 20% blend, the efficiency drops to 34.174%. A 15% blend results in an efficiency of 38.348%, and a 10% blend yields 35.46% efficiency. The brake thermal efficiency with regular diesel is 12.144%, but when using a 20% blend, it increases to 13.83%. A 15% blend results in an efficiency of 11.94%, and a 10% blend leads to 14.288% efficiency. The average indicated thermal efficiency with regular diesel is 30.30%, but when using a 20% blend, it increases to 40.025%. Using a 15% blend results in an efficiency of 33.64%, and with a 10% blend, the efficiency is 39.31%. These findings demonstrate the impact of different fuel blends on the engine's performance. Although there is a difference, it is not substantial. Additionally, properties such as density, flash point, and fire point are within acceptable limits. Upon analyzing the engine's performance during the load test, it was observed that the engine operated similarly to when running on normal diesel. There was no excessive smoke, vibrations, or noises. Overall, the engine ran smoothly and safely. In summary, the engine demonstrated satisfactory performance when using algae biodiesel with certain blends.

The downside is that the production cost and time required are quite high. Converting algae into powder necessitates expensive equipment. After that, the powder needs to be turned into oil, followed by the transesterification of the oil to obtain diesel. The soxhlet extraction process for oil extraction is time-consuming, taking about 5-6 hours to obtain 20ml of oil. Additionally, another costly equipment called a roto-evaporator is needed to obtain pure oil. The equipment for the soxhlet setup and transesterification setup is fragile, requiring careful handling and experienced workers. Transesterification is also a time-consuming process. Moreover, the reagents used for soxhlet extraction and transesterification, such as hexane and methanol, are expensive and flammable, necessitating thorough care and well-equipped safety precautions.

The production process for algae-based biodiesel is both expensive and time-consuming. It requires a large amount of wet algae to produce a small quantity of biodiesel and demands careful handling, experienced workers, and additional energy. However, the resulting biodiesel can be used safely in engines. In conclusion, it is not currently economical to produce biodiesel from algae, but further research, development, and improvements may make it more feasible in the future.

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