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Experimental Investigation of Performance and Emission Characteristics of Biofuel Extracted From Algae

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Abstract: The aviation industry is one of the major contributors for the green house gases. As air travel has become inevitable in this modern era, and fossil fuel usage is not sustainable, it is essential to produce renewable fuel and commercialize it to reduce the green house gase missions. The conventional fuels like Jet A1 causes atmospheric pollution due to the release of its exhaust that contain elements like CO, NOx etc. Biodiesel is an alternate renewable, bio degradable, nontoxic fuel similar to conventional fossil fuel. Biodiesel emitsfewer air pollutants, green house gases other than oxides of nitrogen and easier to treat when compared with fossil fuels. It has also gained much attention in recent years due to its eco-friendly nature, non-toxic characteristics, bio degradability and lower net carbon cycle compared to conventional diesel fuels. So in this current study it focuses on the production of biodiesel from algal oil and waste cooking oil. Recycled waste cooking oil is harmful to health, also it is not environment friendly to dispose of used cooking oil. The best solution is use it for industrial purposes, namely to convert it into biodiesel. Also, biodiesel from green energy source algae is gaining tremendous attention for eco-friendly and economically aspect. The study focuses on the production of algal fuel with the aid of suitable catalystunder given experimental conditions. For this objective, three blends are prepared B10, B15, and B20 in which we blend algal fuel, waste cooking oil and conventional diesel at different proportions and analyse the emission and performance characteristics in comparison with Jet A1. From the results it was clear that the CO, NOx, HC emissions at full load conditions are lower compared to Jet A1. The engine performance also become comparable to Jet A1 when the algal fuel ratio increases. Thus helps in eliminating the impacts caused by the green house gases by using these fossil fuels.

Keywords: Microalgae; Algal fuel; Biodiesel; Biodiesel blending; Waste Cooking Oil; Transesterification, Aviation, Jet A1; Biofuel extraction.

I. INTRODUCTION

Presently, three major issues are in front of human beings: hunger, the lack of energy and the deterioration of the environment. It is obligatory to fight with all the three vehemence simultaneously, because any one of these is capable to extinct out our civilization. Up till now energy requirements has been met by the fossil fuels (coal; oil; gas). Globally consumption of energy has been almost doubled up in recent times and fossil fuels share more than 80%of the primary energy consumed in the world, and 57.7% of that amount is used in the transport sector.

Transportation is important for humans from beginning of time but its relevance in fast communication has improved all the more now. Humans always desire to move faster that led to the breaking improvements in the field of automobile engine which runs on fuel, the commonly used fuel is crude oil from which various fuels like Petrol, Diesel, Kerosene and are extracted through refining process. By engine faster travel was made possible by depending on conventional fuels includes petrol and diesel. These conventional fuels on combustion in the engine produce exhaust which is harmful to the environment creating major problems for all plants and animals. Although the use fossil fuels may seem beneficial to our lives, this act is playing a role on global warming and it is said to be dangerous for future and hence the production of an alternative fuel becomes necessary in transportation industry and one such alternative is the use of biofuels. Today there are many kinds of research are done in the effective production of biofuel.

A biofuel is a fuel that is produced through contemporary processes from biomass. Biofuels include ethanol (from vegetable oils and liquid animal fats), green diesel (from algae and other plant sources) and biogas (from animal manure and other digested organic material) biofuel is considered to be a source of renewable energy, unlike fossil fuels such as petroleum, coal, and natural gas. Biofuels are most useful in liquid or gaseous forms because they are easier to transport, deliver and burn cleanly. As a renewable energy source, plant-based biofuels in principle make little net contribution to global warming and climate change. Biofuels can also be produced from water based algae.

II. MATERIALS AND METHODS

A. 2.1Test Fuels

This framework is about the experimentation for the preparation of biofuel from algae. Here we use both WCO and algal blends for improving the performance and emission characteristic of diesel engine. These biodiesel and blends are explained further as follows:

2.1.1 Algal Fuel: Algae has been discovered as an extremely suitable biofuel because of the surprisingly high ratio of yield to the area required for growth. Algae fuel, algal bio-fuel, or algal oil is an alternative to liquid fossil fuels that uses algae as its source of energy-rich oils. Here, we prepare the algal fuel as an alternative for biofuel. In this we using BG-11 medium because it has advantages over other algal medium. The blue green algae may dominate an increase excessively in water when: nutrient level, particularly phosphorous and nitrogen are sufficient to support the growth.

The algal stained was obtained and experiment was done. The inoculation for cultivation of algal species is allowed to grow in the presence of light and aeration. After preparation of BG-11 medium it can be sterilized by three methods plasma gas sterilization, autoclave, vaporizes hydrogen peroxide process. Here we use autoclave process, by boiling the prepared medium in a cooker under 180 C for 30 minutes. The pouring the medium in 500ml in a conical flask up to 350ml and we add our algal culture to it, Then we will close it tightly and place under the light. After 2 weeks the culture is separated using separation funnel and then we will dry the algal solution in hot air oven under 60 C to 70 C. After the removing moisture content, the algae flakes is subjected to oil extraction process to derive algal oil. Here we use Soxhlet extraction technique is adopted.

Soxhlet process, we place the round bottom flask and poured 150ml of methanol as solvent, set the heating mantle at 60 C. The algal flakes are poured into a filter paper and is placed inside the by-pass condenser. On top of by-pass condenser we place the reflux condenser provided with 2 ends for water inlet and outlet. When the mantle get heated the methanol get evaporated in the form of steam and move upwards, become water droplets moves downwards and gets accumulated in the top of the filter paper filled with algal flakes. The more steam in the form of water droplets become more viscous move towards the round bottom flask. Take out the algal fuel from the round bottom flask after the process is finished and do the further testing's.

Free fatty acid test is also done here to identify whether the oil is to undergo esterification or trans-esterification. Esterification is nothing but repeating the process of trans-esterification for two times. The 5 ml of sample oil, 25ml of isopropyl alcohol with 4 drops of 0.1 normality NaOH is added and stirred. If the value is above 4% esterification is adopted and if the value is below 4 % we adopt trans-esterification, here had done trans-esterification of algal oil and waste cooking oil. Trans-esterification is a process which convert oil into combustible fuel, by heating and swirl withn500-700 rpm for 8 hours, we will get algal oil biodiesel. After this the product is allowed to settle to collect the less dense biodiesel at the top and the denser glycerol at the bottom in the separating funnel. For this experimentation three fuel blends are prepared B10(AO5WCO5CD90), B15(AO7.5WCO7.5CD85),B20(AO10WCO10CD80). Various physical properties of JET A1, Waste cooking oil methyl ester and blends such as viscosity, density, flash point, calorific value etc. were determined using ASTM standards.

2.1.2 Waste Cooking Oil: This oil is gathered from the canteen of Satyabhama Institute of Science and Technology, Chennai. The WCO oil is considered as the sustainable complement as a fuel for diesel engine. Collected WCO may contain particulate matter and other impurities. Such impurities are removed by filtering the WCO. It was necessary to purify it before conversion to methyl esters. For that purpose a pre-treatment process, including filtration and dewatering, was carried out. Initially the waste oil was filtered using bag filter to remove food particles and stored in a can. The purified waste vegetable oil need to convert as methyl ester. It is carried out through either esterification or trans-esterification. It is necessary to Free Fatty acid content to determine whether esterification or trans-esterification. One more approach for reusing the WCO as biodiesel is by means of trans-esterification using NAOH catalyst. There is a negative influence made by the free fatty acids in WCO over the biodiesel production economy for trans-esterification with increase of overhead on alcohol.

2.1.3 Jet A1 : JET A-1 is a petroleum distillate blended from kerosene fractions having Aromatics below 20 % v/v, Total Sulphur below 0.25 % mass, Mercaptan Sulphur below 0.002 % mass, freezing point below - 47 0 C and a flash point above 38 0 C. It contains Static Dissipater additive STADIS 450. JET A-1 is the principle fuel used for jet turbine engines.

Table 1 Fuel properties

Fuel	Calorific value (cal/g) (ASTM D4809)	Density (g/cc) at 40^{0}C (ASTM D4057)	Kinematic viscosity (cSt) (ASTM D445)	Flash point (^{0}C) (ASTM D93)	Fire point (^{0}C) (ASTM D93)	Cloud point (^{0}C) (ASTM D97)	Pour point (^{0}C) (ASTM D97)	Acid value (NaOH/g of oil)
WASTE COOKING OIL	8522.978	0.875	4.07	189^{0}C	202^{0}C	8^{0}C	2^{0}C	0.218
ALGAL OIL	9862	0.898	4.75	140^{0}C	158^{0}C	1^{0}C	3^{0}C	0.48
JET A1	10892.23	0.766	0.434	43^{0}C	56^{0}C	Not significant	Not significant	0.11

2.2 Test Engine and Instrumentation.

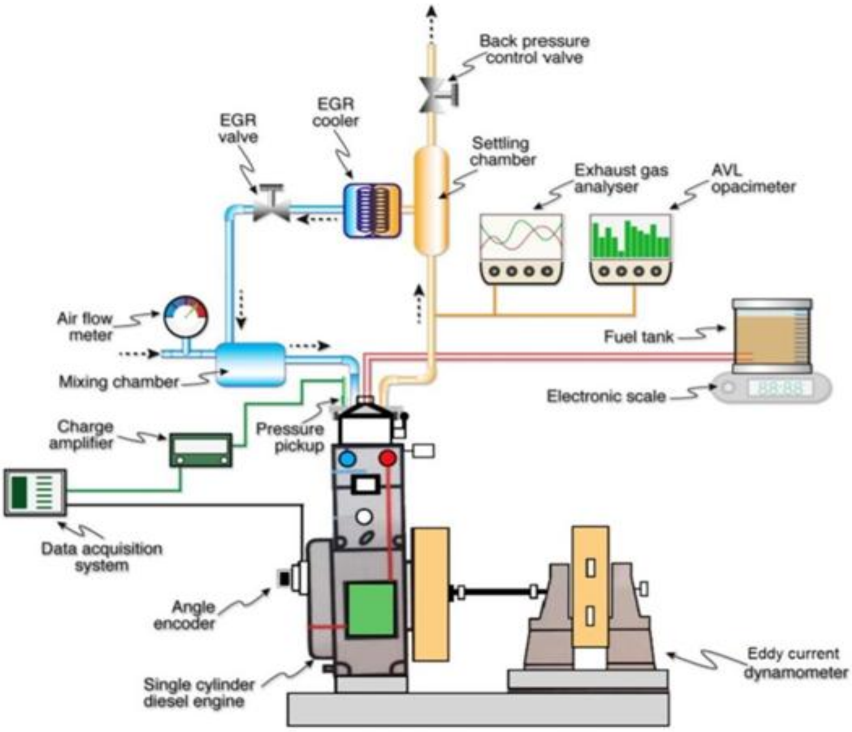

Fig. 1. Experimental setup layout representation

Computerized VCR engine is used to find the performance and combustion parameters of Variable Compression Ratio Petrol Engine. The compression ratio of the engine is variable from 2.5:1 to 10:1.A unique provision is been made to vary the spark timing of the engine. Wide range of combustion studies can be conducted with the help of this setup. Engine Combustion and performance parameters like Actual volume of Air, Volumetric Efficiency, Specific fuel consumption (SFC), Brake Thermal Efficiency, Brake power, Heat Balance chart, mechanical efficiency, Frictional Power , indicated Power, PV and P-θ diagrams, Mass Fraction Burnt Angle, Estimated End of Combustion Angle (EEOC), Gross IMEP, Maximum Heat Release Rate, Maximum Heat Release rate crank angle, Maximum pressure rise rate, Maximum pressure rise rate crank angle, Maximum pressure, Maximum pressure crank angle, Start of Combustion, Total heat release, Ignition delay, ignition duration can be studied. The setup consists of single cylinder 4 stroke, VCR (variable compression ratio) electric star diesel engine connected to eddy current type dynamometer for loading. The compression ratio can be changed without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. Setup is provided with necessary instruments for combustion pressure and crank angle measurement. The setup enables the study of VCR engine performance with EGR for brake power, frictional power, BMEP, IMEP, brake thermal efficiency.

Table 2: Engine Specifications

Make and model	**Kirloskar, TV1 make, 4-Stroke Diesel**
Number of cylinders	One
Cooling system	Water-cooled
Combustion chamber	Hemispherical open type
Piston Shallow	Bowl-in type
Lubricating oil	SAE40
Compression ratio	18:1(VARIABLE)
Clearance volume, cm3	38.35
Stroke, mm	110
Connecting rod length, mm	238
Bore, mm	87.5
Swept volume, cm3	661
Fuel injection pump	MICO inline, with mechanical governor
Injection type	Direct Injection
Rated power, kW	5.2
Rated speed, rpm	1500
Spray-hole diameter, mm	0.25
Valve diameter, mm	34.2
Injection pressure, bar	210
Maximum valve lift, mm	10.1
Number of Nozzle holes	3
Injection timing, CA bTDC	23°
Spray cone angle, °	110
Needle lift, mm	0.25

2.3 Test Procedure

The testing was carried out under four different percentages of rated load of engines given as 25%, 50%, 75% and 100%, correspondingly. All over the study, the injection pressure has been maintained as constant. The test engine's injection time that was recommended by the manufacturer is 23° CA bTDC. The lubricating oil temperature has been sustained within the range of 85° to 90°C. Before the documentation of the readings, the engine is promoted to run for 10mins for the attainment of better stabilization.

III. RESULT AND DISCUSSIONS

3.1 Performance Parameters

Brake Thermal Efficiency:

A comparison of brake thermal efficiency obtained at different load conditions shown in figure 1. At full load condition, the brake thermal efficiency of Jet A1, B10, and B15 B20 is 33.05, 31.09, 31.62, and 32.16 respectively. As the load increased, the brake thermal efficiency of the different blends also increased. With an increase in engine load, the brake power of the engine increased at a higher rate than the rate of increase of associated losses, thus resulting in the increase of thermal efficiency. This is due to lower viscosity and good atomization properties

The thermal efficiency of the blends were found to be lower at all load conditions compared to Jet A1, but these efficiencies are quit comparable to Jet A1. It is clear from figure that B20 blend has higher BTHE at all load conditions compared to other blends.

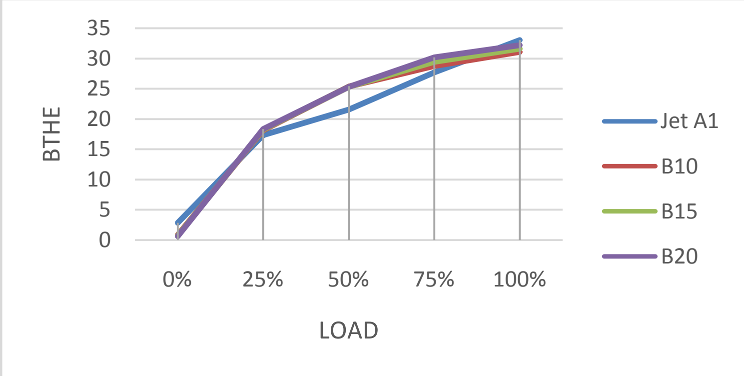

Figure 2: Comparison in Break Thermal Efficiency of Jet A1 and blends

Specific Fuel consumption:

The blends have higher specific heat value compared to Jet A1 fuel, the study of brake specific fuel consumption (SFC) gives a better explanation for the energy utilization of various fuels. Figure 2 presents the variation of SFC for Jet A1 and blended fuels, at different load conditions. With an increase in load, the SFC decreased for all of the fuels. At full load, the SFC for Jet A1, B10, B15, and B20 is .1, .28, .27, and .27Kg/kWh respectively. From figure 2 it is clear that blend B20 has lower SFC at all loads compared to other blends.

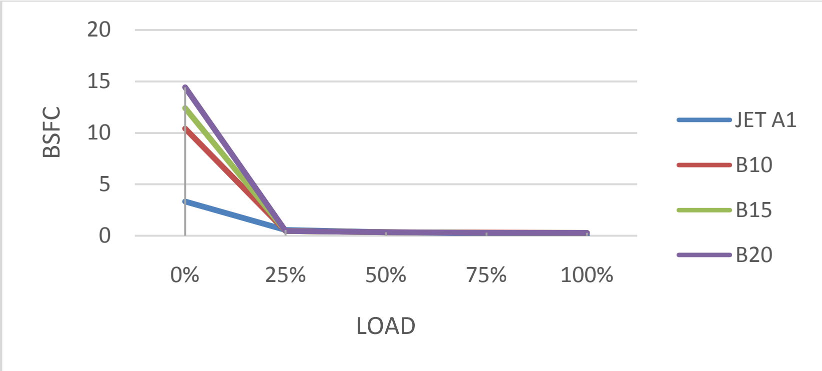

Figure 3: Comparison in Specific Fuel Consumption of Jet A1 and blends

3.2 Emission Parameters

Carbon Monoxide Emission (CO): The variations of CO emission with respect to different load conditions for Jet A1 and blended fuels shown in figure 3. All blends showed a significant increment of CO. This is because of low atomization and the combustion of the oxygen-rich blend.

At full-load conditions Jet A1, B10, B15, and B20 produces CO emissions of 0, .212, .204, and .196% by volume respectively. At higher loads, like 50%, 75% etc. B20 has lesser emission compared to other blends.

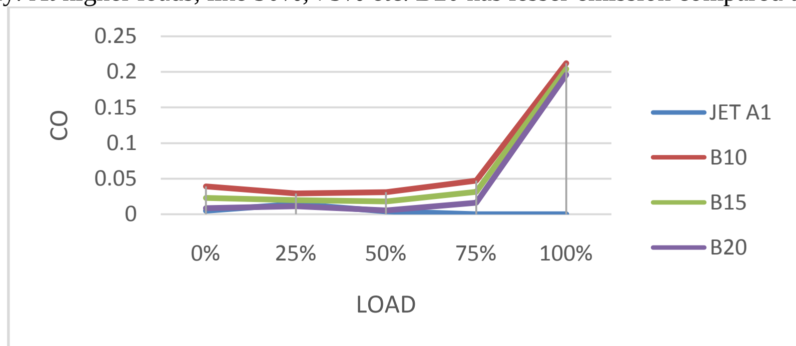

Figure 4: Comparison in Carbon Monoxide Emission for Jet A1 and blends

Hydro Carbon Emissions: From figure 4 it is clear that HC emission of all blends is more compared to Jet A1. Comparing the blends as the blending percentage increases HC emission increases due to the increment of carbon content in fuel.

At full load conditions, the variation of HC emission for Jet A1, B10, B15, and B20 is 35, 114, 101, and 88 respectively. At higher loads above 50% B20 has lesser HC emission compared to other blends.

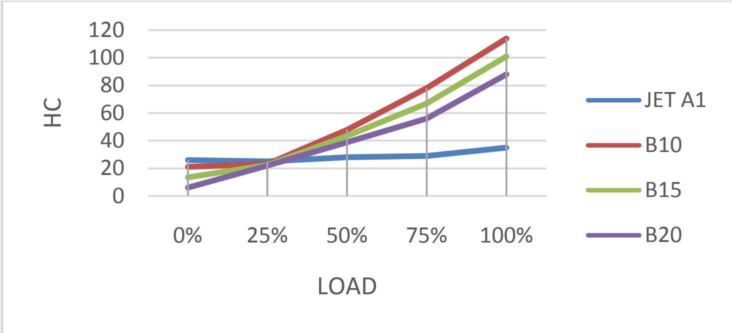

Figure 5: Comparison in Hydro Carbon Emission for Jet A1 and blends

Nitrogen Oxide (NOx) Emission: The figure 5 gives the variation of NOx emission for Jet A1, and blended fuels at different load conditions. The emission of NOx is due to the reaction of oxygen and nitrogen under high temperature conditions. The emission of NOx increases by increasing the reaction temperature and oxygen content. Also, the incomplete combustion of the fuel mixture leads to greater emission of NOx due to the deposition of carbon on the walls of the combustion chamber, piston crown and valves, which acts as an insulator, increasing the temperature inside the combustion chamber, which also leads to early ignition resulting in knocking of the engine.

The availability of oxygen and complete combustion of the fuel lead to higher temperature and less carbon deposited on the internal walls of the cylinder, which improves the heat transfer resulting in lower NOx emission. As the load increased, NOx for B20 blended fuels increased. At full load conditions, the variation of NOx emission for Jet A1, B10, B15, and B20 is 1259, 1630, 1643.5, and 1657 respectively. At higher load ranges above 50% B10 has lesser NOx emission compared to other blends.

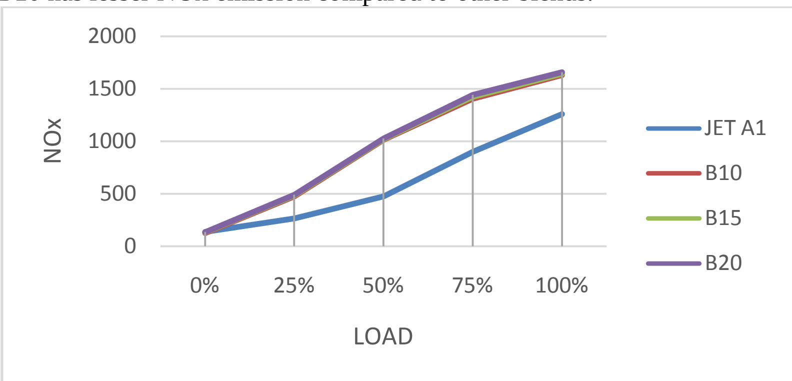

Figure 6: Comparison in Nitrogen Oxide Emission for Jet A1 and blends

IV. CONCLUSION

In this work, an attempt has been performed to implant the alternate fuel for Jet A1using algal fuel blended with waste cooking oil and conventional diesel. For this three blends are introduced and its emission and performance parameters are compared with Jet A1. The final conclusion obtained are given below:

- Algal oil blended with waste cooking oil and conventional diesel can be replaced for jet engine in aviation industry in order to improve the emission parameters.
- Considering the performance parameters for 50% load condition, the BTHE value for B10 is more compared to other blends and SFC value of all the three blends remains constant. In the case of emission parameters B20 have lower carbon monoxide and hydro carbon emission but B10 have lower nitrogen oxide emission compared to other blends
- Considering the performance parameters for 75% load condition, the BTHE value is more for B20 and SFC value is less for B20 compared to other blends. In the case of emission parameter B20 have lower

carbon monoxide and hydro carbon emission but B10 have lower nitrogen oxide emission compared to other blends.

- Considering the performance parameters for 100% load condition, the BTHE value is more for B20 and SFC value is less for B20 compared to other blends. In the case of emission parameter B20 have lower carbon monoxide and hydro carbon emission but B10 have lower nitrogen oxide emission compared to other blends.
- From all the above observations of engine performance we can conclude that B20 have higher break thermal efficiency (BTHE) value at the same time B20 have lower specific fuel conception (SFC) compared to other blends also for the emission parameters, we can conclude that B20 have lower carbon monoxide (CO) emission and lower hydro carbon (HC) emission values but the nitrogen oxide (NO_x) emission value of B20 is very high compared to other blends.
- This study confirmed that as the blending ratio with the addition of algal oil, and waste cooking oil methyl ester increases the engine performance as well as the emission characteristics also increases and hence algal oil-based biofuels have good potential to replace the Jet A1 fuel in the near future.

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