ANALYSIS OF COMBUSTION PROCESS OF ALGAE OIL FUELLED VCR ENGINE USING LAMBDA (Λ) CHARACTERISTICS

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Abstract — Increasing pollution levels day by day across the globe have emerged as a major concern and posing threats to existence of human life. All researchers, environmentalists and technocrats especially engineers involved in industrial operations and in designing automobiles are facing a lot of work pressure to provide feasible and workable solutions to the world for reducing pollution to the acceptable level which may further reduce global warming. Bio-fuels extracted from algal biomass have proved to be one of the promising biodiesel with reduced emissions of harmful gases like CO, CO_2, O_2, Hydrocarbons and Oxides of Nitrogen (NO_x) and the characteristics obtained are almost comparable with pure diesel with almost no modification in existing engines. Lambda calculation in emission testing provides information about the type of mixture with respect to availability of oxygen for combustion and thereby engine performance is determined with respect to normal or abnormal operation. It also helps in troubleshooting of engine components especially related to piston, piston rings and cylinder.

Key words — Biomass, Green House Gases, Alternative Fuel, Lambda Characteristic etc.

1. INTRODUCTION

The world is facing a serious problem of global warming which is increasing day by day and posing threat to the existence of human life in the coming years. Increasing levels of pollution especially from industries and automobiles have come under scanner and if not checked appropriately will disturb the ecological balance causing threats to all forms of life including aquatic. Emissions of green house gases like Carbon Dioxide (CO_2), Carbon Monoxide (CO) and methane (CH_4) form a thick layer in our lower atmosphere preventing escaping of heat from earth to upper atmosphere. The trapped heat increases the temperature of the earth and causing glaciers to melt at a faster rate. Melting of ice glaciers increases the water level of seas and oceans causing inundation of lands thereby reducing the area of natural habitat of human beings and animals.

The emissions have increased due to continuous use of fossil fuels like coal, diesel, gasoline etc. Simultaneously, depletion of fossil fuel levels and limited availability of it made the price of crude oil to go high thereby limiting affordability for a common man. Ill effect of using fossil fuels in terms of emissions of green house gases and also limited availability, engineers and environmentalists have joined together in finding solutions by using alternate fuels extracted from several renewable energy sources like used cooking oils, animal fats, algal biomass and also from various seeds and husks.

Biodiesels extracted from Chlorella microalgae have also been proved to be one the strongest competitor as alternative fuel. The biodiesels derived from biomass cannot be used directly in the internal combustion engines due to difference in combustion properties like flash point, density, kinematic viscosity etc. in comparison to fossil fuel diesel. Using additives like Ethanol (C_2H_5OH), Methanol (CH_3OH), and Diethyl Ether (DEE) in required proportion improve the combustion properties and thereby effective combustion can be achieved.

Cylinder pressure in the cylinder [1][3] plays an important role in combustion of the mixture. A computational model is described for determination of cylinder pressure. More pressure in the cylinder means through mixing of air and fuel thereby good combustion can be achieved. Increase in injector nozzle pressure also increases atomization which further allows combustion to be completed in lesser time.

Exhaust Gas Recirculation (EGR) [2][5][6][7] is the technique mainly used to reduce emissions of oxides of nitrogen (NOx). Though it reduces emissions of NOx allowing combustion at lower temperature in the engine, it reduces power of the engine due to mixing of waste gases. Hence, only a certain proportion of EGR is only accepted for its utilization in the engine.

Various blends – B20, B40 and B100 of Chlorella microalgae oil is used for combustion in Variable Compression Ratio (VCR) Kirloskar diesel engine which is generally used for testing fuels and finding out combustion and emission characteristics using 5 gases analyzer. Various blends of biodiesels is used one by one in the engine and the combustion and emission characteristics are obtained using automated software integrated with the computing system connected for measuring various performance parameters.

The Lambda (Λ) characteristics measured for each biodiesel samples and pure diesel D100 are compared for their variations and a suitable sample of fuel is suggested for further experimentation for its use as alternative fuel in diesel engines without major modifications.

2. Chlorella Microalgae Oil

Chlorella microalgae can be grown in fresh water as well as in saline water. It can be grown in abundance with controlled climatic conditions. In many countries like Japan and

Taiwan, the alga is also used as a food supplement. It also forms a part of medicine. Its pungent smell limits its more use in food products. The oil extracted from this alga is found to be suitable for use as alternate fuel in diesel engine but do not produce similar power as is produced by pure diesel engine. In order to improve the combustion properties, additives are to be used in suitable proportion.

3. Comparison of Combustion Properties of Biodiesel and Pure Diesel

Observing safety precautions and laid down laboratory standards, the pure biodiesel (B100) produced from microalgae is used for testing chemical properties. The properties of pure diesel (D100) are as specified by ASTM Standards.

Sl. No.	**Fuel Samples**	**D100 (%)**	**B100 (%)**
1.	B100	0%	100%
2.	B40	60%	40%
3.	B20	80%	20%
4.	D100	100%	0%

Table 1: Chemical Composition of Fuel Samples.

	Diesel and Biodiesel	**D100**	**B100**
1.	Kinematic Viscosity (cst)	2 - 4.5	4.07
2.	Density ($Kg/m^{3)}$	820 – 860	896
3.	Fire Point (^0C)	210	119
4.	Flash Point (^0C)	> 35	108
5.	Calorific Value (kj/kg)	46000	39321

Table 2: Chemical Properties - D100 and B100.

4. Lambda (Λ) Characteristics Measured as emission Characteristic

Lambda (Λ) characteristics measurement in emission characteristics provides analysis of types of mixture (chemically correct, lean and rich) combusted in the engine cylinder to produce brake power. The analysis of lambda (Λ) values obtained are compared with the values obtained for emission of Carbon Dioxide (CO_2), Carbon Monoxide (CO) and Hydrocarbons (HC) for finding out problems if any in the proportion of air and fuel in the mixture supplied to the engine. The presence of oxygen in the exhaust gas indicates some problems or defects in the engine requiring attention and corrective action. Hence emission of oxygen needs to be monitored along with emissions of other harmful gases like CO, CO_2, HC and NOx.

Lambda (Λ) characteristic which is an emission characteristic is the ratio of the actual oxygen content in the fuel inside the cylinder at different loads and theoretically calculated content of the oxygen should be available for combustion.

In normal conditions, for complete and perfect combustion, air/fuel ratio required is approximately 14.7:1 (by weight). The value of Λ will be greater than one (>1.00) if the air which contains oxygen and nitrogen gases as major constituents are more and is applicable for lean mixtures. The value of Λ will be lesser than one (<1.00) if the air in the mixture is less and is applicable for rich mixtures. The value of Λ will be equal to one (1.00) if the air in the mixture is same as theoretically required and is applicable for chemically correct mixtures.

For example, a lean mixture with air/fuel ratio 15.5:1,

$\Lambda = 15.5/14.7 = 1.05$

For a rich mixture with air/fuel ratio 12.2:1,

$\Lambda = 12.2/14.7 = 0.83$

For a chemically correct mixture with air/fuel ratio 14.7:1,

$\Lambda = 14.7/14.7 = 1.00$

In the case of value of Λ given, the air/ ratio can be found by multiplying the given value with 14.7. For example, if Λ is 1.6, then air fuel ratio is 14.7 x 1.6:1 i.e. 23.52:1.

By comparing the Lambda (Λ) values obtained for a specific fuel with the emissions of CO, CO_2, and Hydrocarbons (HC), the fault in the engine components can also be detected. For example, if there is a faulty piston ring which allows engine oil from crankcase to seep inside the cylinder during its reciprocating motion and combustion in the cylinder, the emissions of CO and CO_2 in exhaust gases will be more due to presence of unburned oil.

5. ENGINE USED FOR DETERMINING EMISSION CHARACTERISTICS

Four stroke, single cylinder, water cooled and variable compression ratio (VCR) engine is used for testing the biodiesel and pure diesel for combustion and emission characteristics.

Figure 1: Kirloskar Make – Single Cylinder Diesel Engine

1.	Length of Connecting Rod	234.00 mm
2.	Swept Volume	661.45 cm^3
3.	Cylinder Diameter	87.50 mm
4.	Brake Power	5.20 kW at 1500 RPM
5.	Length of Stroke	110.00 mm
6.	Compression Ratio	17.50: 1

Table 3: Engine Specifications.

6. Experimental Works for Determining Lambda (Λ) characteristic

6.1 Lambda (Λ) Characteristics - D100 vs B100

The Lambda (Λ) values obtained during experimentation in the VCR engine for B100 and D100 are as given in table 4.

BP in %	D100	B100
0	8.11	6.943
25	3.716	3.649
50	2.487	2.509
75	1.933	1.921
100	1.49	1.438

Table 4: Λ values - D100 and B100

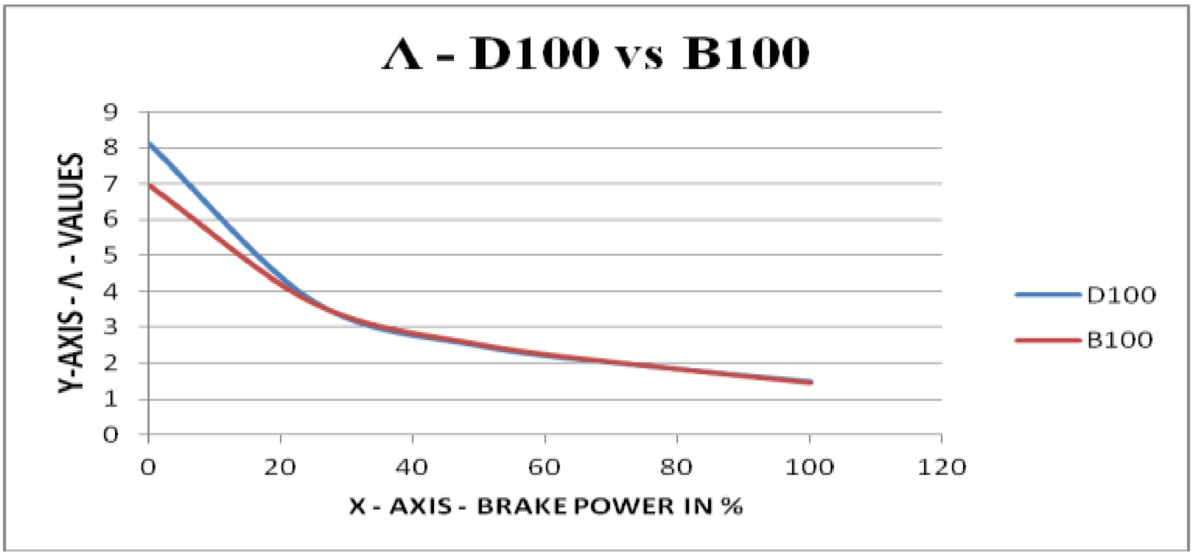

Figure 2: Lambda (Λ) characteristic for D100 and B100

With increase in load, the Lambda (Λ) characteristics for both D100 and B100 have decreased which shows clearly the presence of less amount of unburned fuel in the exhaust gases in higher loads. When compared with D100 values, Λ - values for B100 are lesser and it indicates comparatively good combustion in the cylinder and presence of high lean mixtures in the cylinder especially at no load condition in both D100 and B100.

Due to high density and low calorific value, B100 is not found suitable to use directly in the diesel engine as combustion characteristics are not found satisfactory and closer to the characteristics obtained with D100 despite of lesser Lambda (Λ) values.

6.2 Lambda (Λ) Characteristics - D100 vs B40

The Lambda (Λ) values obtained during experimentation in the VCR engine for B40 and D100 are as given in table 5.

BP in %	D100	B40
0	8.11	7.675
25	3.716	3.729
50	2.487	2.636
75	1.933	1.971
100	1.49	1.464

Table 5: Λ values - D100 and B40

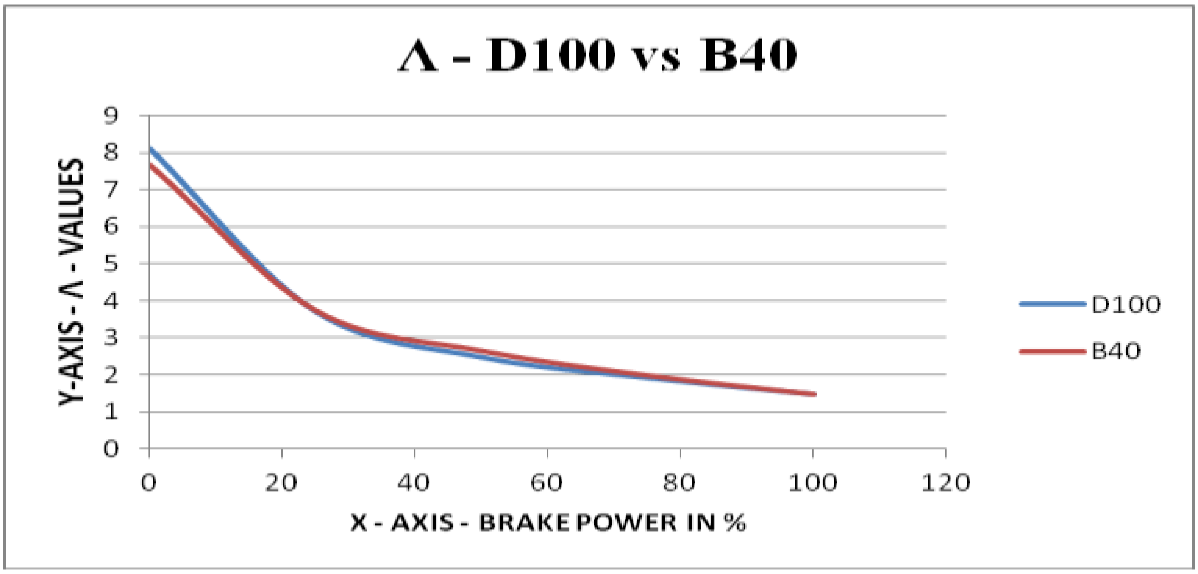

Figure 3: Lambda (Λ) characteristic for D100 and B40

The Λ – values for B40 are lesser than D100 but more than B100. This increase is due to presence of 60% of D100 in B40 biodiesel and due to which presence of carbon has increased leading to improper combustion. A high lean mixture availability in the cylinder leads to improper combustion due to high density and improper atomization.

6.3 Lambda (Λ) Characteristics - D100 vs B20

The Lambda (Λ) values obtained during experimentation in the VCR engine for B20 and D100 are as given in table 6.

BP in %	D100	B20
0	8.11	7.881
25	3.716	3.628
50	2.487	2.478
75	1.933	1.885
100	1.49	1.481

Table 6: Λ values - D100 and B20

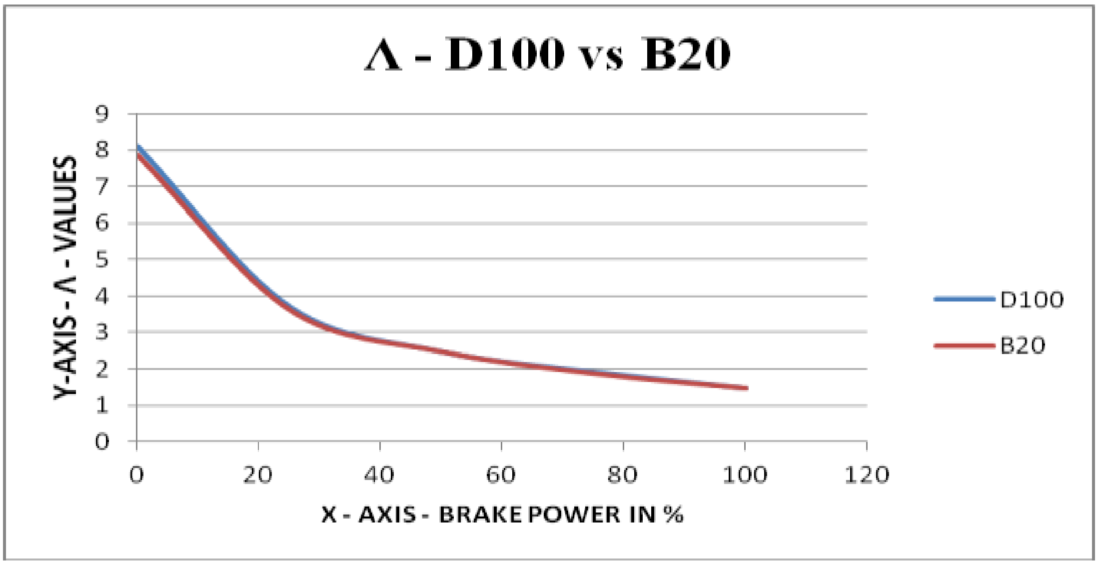

Figure 4: Lambda (Λ) characteristic for D100 and B20

The Λ – values for B20 are lesser than D100 but more than B40 at 0%, 75% and 100% engine loads. At 25% and 50% engine loads, the values are lesser than B40. This increase is due to presence of 80% of D100 in B20 biodiesel and due to which presence of carbon has increased leading to improper combustion and presence of unburned fuel in the exhaust gases.

7. Results

7.1 Variations - Lambda (Λ) Characteristics - D100 vs B100

The variations in Lambda (Λ) values for B100 and D100 in % obtained during experimentation in the VCR engine and on analysis of the values are as given in table 7.

BP in %	Variation in %– D100 vs B100
0	7.25
25	2.73
50	1.48
75	0.94
100	0.52

Table 7: Variations in Λ values - D100 and B100

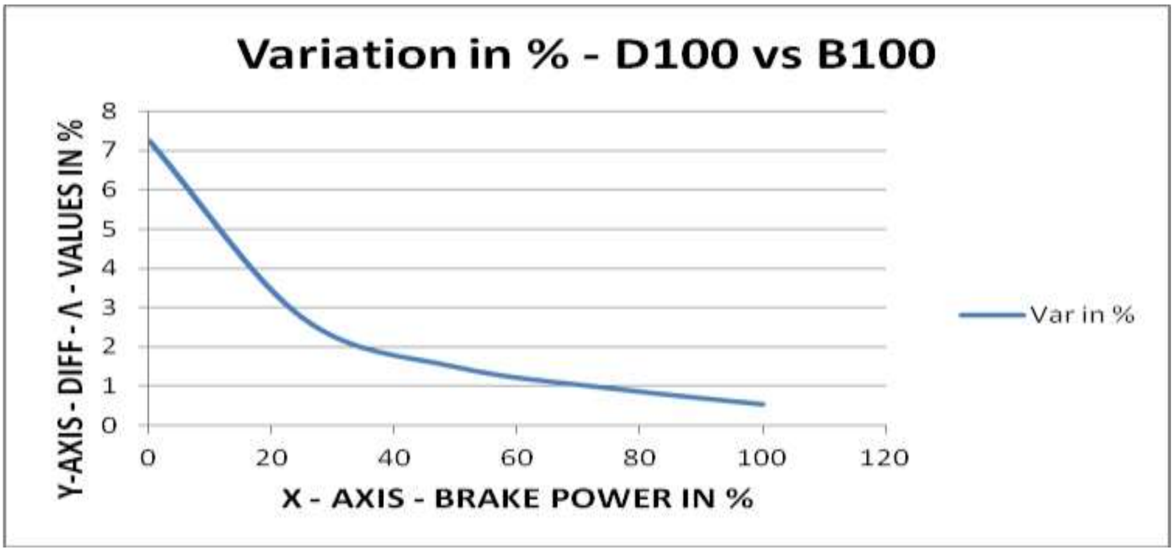

Figure 5: Variations in Lambda (Λ) characteristics in % for D100 and B100

In comparison to D100, performance of B100 is found better at all engine loads. Though in all ranges of engine loading, high lean mixture especially in lower loads are present for both B100 and D100. Maximum variation of 7.25% is found at 0% engine load and minimum variation of 0.52% is found at 100% engine load.

Though Lambda (Λ) characteristic indicate better values for B100 than D100 but B100 cannot be used in engine directly as other mechanical performance parameters are not similar to the values obtained for D100.

7.2 Variations - Lambda (Λ) Characteristics - D100 vs B40

The variations in Lambda (Λ) values for B40 and D100 in % obtained during experimentation in the VCR engine and on analysis of the values are as given in table 8.

BP in %	Variation in %– D100 vs B40
0	7.16
25	2.71
50	1.43
75	0.91
100	0.51

Table 8: Variations in Λ values - D100 and B40

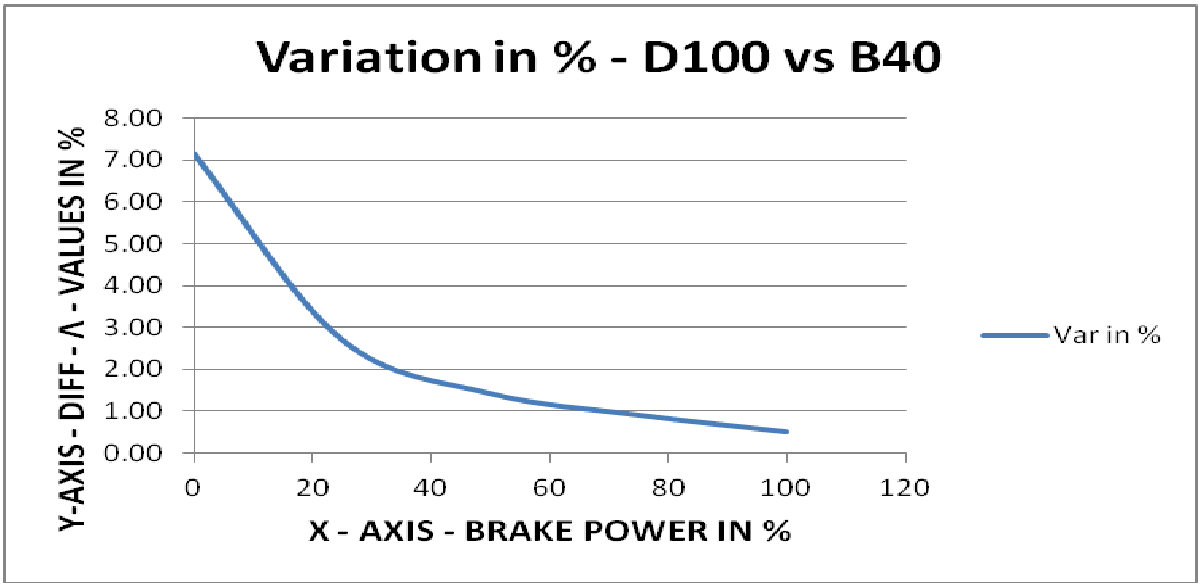

Figure 6: Variations in Lambda (Λ) characteristics in % for D100 and B40

In comparison to D100, performance of B40 is observed as better at all engine loads. Lean mixture conditions at all loads shows presence of less oxygen for combustion. Maximum variation of 7.16% is found at 0% engine load and minimum variation of 0.51% is found at 100% engine load.

Though Lambda (Λ) characteristic indicate better values for B40 than D100 but B40 is not suitable to use in the engine directly. The mechanical performance parameters produced with B40 biodiesel are not closer to the values obtained for D100.

7.3 Variations - Lambda (Λ) Characteristics - D100 vs B20

The variations in Lambda (Λ) values for B20 and D100 in % obtained during experimentation in the VCR engine and on analysis of the values are as given in table 9.

BP in %	Variation in %– D100 vs B20
0	7.14
25	2.74
50	1.49
75	0.96
100	0.50

Table 9: Variations in Λ values - D100 and B20

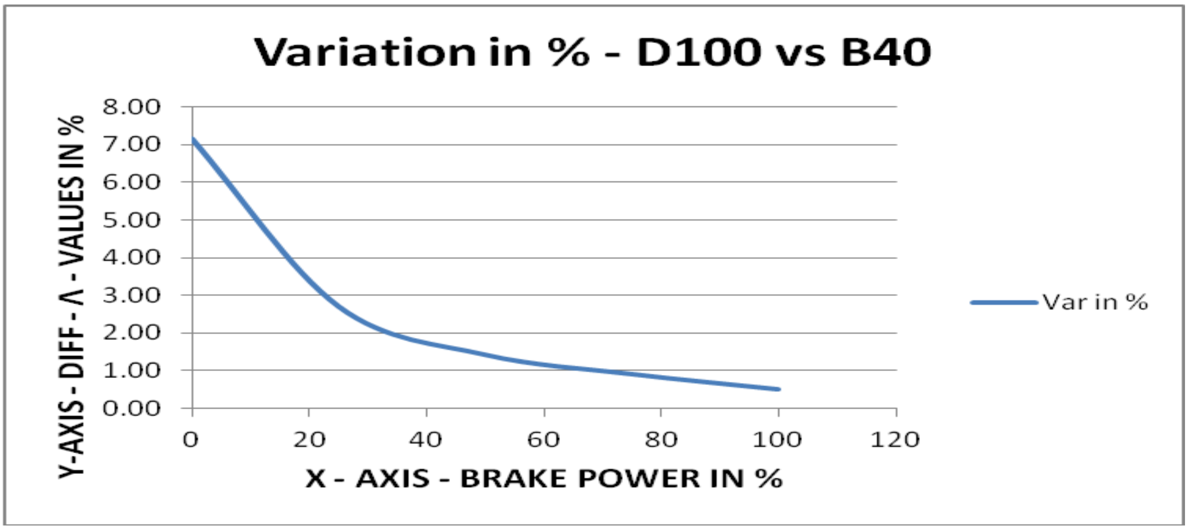

Figure 7: Variations in Lambda (Λ) characteristics in % for D100 and B20

In comparison to D100, performance of B20 is observed as better at all engine loads. Lean mixture conditions at all loads shows presence of less oxygen for combustion even for D100. Maximum variation of 7.14% is found at 0% engine load and minimum variation of 0.50% is found at 100% engine load.

Lambda (Λ) characteristic indicates better and comparable and almost similar values for B20 when compared to D100 and hence B20 can be selected as an experimental fuel for further analysis of its combustion characteristics.

8. Discussions

The combustion characteristics of biodiesels can be improved by using additives like ethanol, methanol, diethyl ether etc. which not only provides additional amount of oxygen for complete combustion but also reduces density of biodiesels and kinematic viscosity and increases calorific value. In turn the engine power is increased making the biodiesel more suitable to use as alternative fuel in diesel engines without any major modifications in the engine.

B20 biodiesel can further be considered for analysis of combustion and performance characteristics using additives and even by changing injection pressure which helps in better atomisation for complete combustion.

9. CONCLUSION

The powerful demand in present scenario where global warming has emerged as one of the greatest challenge for all engineers, technocrats and even for environmentalists to provide some promising sources of alternative fuel especially extracted from renewable energy sources and also should be environment friendly. The presence of Carbon dioxide gas in the atmosphere does not produce severe ill effect on health. Presence of it in high amount along with other green house gases like methane, carbon monoxide etc. form a thick layer in the upper atmosphere and thereby preventing escape of heat from earth and cause warming of earth leading to dangerous situation for existence of life on earth.

The biodiesel produced using algal biomass is also one of the promising sources of energy which has the capability to replace fossil fuels like diesel without any major modifications in the existing automobile engines.

The biodiesels B20, B40 and B100 are used as experimental biodiesels for comparing the combustion and emission characteristics with that of pure diesel D100. In this paper, emphasis is given to compare lambda (Λ) values of biodiesels B20, B40, B100 and D100 which indicate presence of rich, lean or chemically correct mixtures during combustion in the engine cylinder. The information regarding mixtures is obtained by comparing lambda (Λ) values recorded during testing of the biodiesel for emission characteristics. The measurement of these values is done by calculating the ratio of amount of oxygen actually present to the amount required for complete combustion. In normal conditions, the standard air fuel ratio for complete combustion is 14.7:1 (by weight).

Though lambda (Λ) values for B100 are found more satisfactory when compared with the corresponding values obtained for pure diesel D100 but combustion characteristics with respect to mechanical performance parameters is not satisfactory making it unsuitable to use it directly in the diesel engine. As the proportion of diesel increased in B40 and B20, the lambda (Λ) values increased and indicated presence of carbon and oxygen in the exhaust gases. It shows incomplete combustion and thereby needs corrective action for making the biodiesels more suitable.

Biodiesel B20 can be considered for further experimentation using additives like ethanol or diethyl ether in suitable proportion for improvement in combustion characteristics by reducing density and viscosity and increasing calorific value which increased almost similar power as produced with D100.

Lambda (Λ) values also provide diagnostic technique to be used for trouble shooting with respect to faults in the engine components especially in piston and piston rings.

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