



# Combustion and Emission Characteristics of Algae Oil Fuelled VCR Engine with Thermal Barrier Coated Piston

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**Abstract** — Increasing level of pollution day by day in atmosphere has developed a worried situation for all. The existence of human life is at risk. The emission of pollutants in the atmosphere especially green house gases have to be minimized immediately in order to prevent any type of natural disaster. Industries and automobile sectors are more responsible in emission of pollutants. The same has to be curbed and brought under control. Using biodiesel has proved to be environment friendly to a great extent. In this paper, the algae oil is used with Zirconium Dioxide ( $ZrO_2$ ) coated piston in order to improve the performance of the VCR engine in which the analysis for combustion and emission characteristics is performed. The considerable improvement in performance is observed with coated piston as more amount of heat developed is utilized for producing useful work.

**Key words** — Coating, Green House Gas, Mechanical Efficiency, Thermal Barrier Coating, Zirconium Oxide etc.

## I. INTRODUCTION

Entire world population is facing a challenging problem in saving the atmosphere with its purity in order to provide a clean and healthy atmosphere required for living happily. In the race of winning forward positions, almost all countries used and still using their natural resources including flora and fauna indiscriminately in setting up of industries and in enhancement of technology for their comfort. In this process, the ill effects of destruction of flora and fauna are absolutely ignored. The result is today's worrying situation where existence of human life and even earth has emerged as a big question and made us almost answerless. The fossil fuel used in industries and automobiles contributes most in emission of pollutants. Technocrats are facing a great challenge as the level of fossil fuel reserves are continuously decreasing and days are not far away when our future generations will learn them as historical facts. It is due to this, several researchers have started testing fuels obtained from biomass. The great advantage of biodiesel produced is low emissions of dangerous pollutants and their production cost is very low as the same can be obtained from easily available plants and algae which can be grown also in abundance. The performance is found to be somewhat lower than the performance of diesel and it needs a researcher to find and develop some suitable methods like addition of additives, using coated piston etc.

Revised Manuscript Received on March 30, 2020.

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The blend B20 of algae oil consisting of 20% algae oil and 80% diesel which is a proven fossil fuel for its utmost performance and emissions is subjected to test and analysis in variable for improvement in performance by using stabilized 200  $\mu m$  zirconium Dioxide ( $ZrO_2$ ) coating on piston crown. Generally the engine rejects heat more and only one third of heat is converted into useful work. The coated piston acts as thermal barrier coating which reduces heat loss and more heat is retained in the cylinder for conversion of the same into useful work.

## II. MICROALGAE

The algae used for extraction and conversion of the biomass into biodiesel are available as freshwater as well as marine algae. In some European countries like Germany, Taiwan, Japan etc. use the algae as food supplement and even in medicines. The algae production can be doubled in less time if grown in controlled conditions.

## III. TBC - ZIRCONIUM OXIDE

Zirconium is a silvery gray transition metal having atomic number 40, mass number 91.224u and melting point 1855  $^{\circ}C$ . The properties of Zirconium match with that of hafnium but it is not as strong as titanium. The metal is highly malleable and ductile and high resistance to corrosion and crack initiation. The metal has its extensive use in corrosive environments. Zirconium Dioxide ( $ZrO_2$ ) which is also known as Zirconia is a white crystalline material. It has high thermal expansion making it suitable for use in high temperature environment.

On testing of engine performance, it is found that almost two third of the heat generated in the cylinder moves out as without doing any useful work. Only one-third of the heat is utilized for conversion into useful work. Thermal Barrier Coating (TBC) on Piston Crown, Cylinder Walls etc. reduces considerable heat loss and thereby making more heat to get converted into useful work. Therefore, increase in brake power and brake thermal efficiency takes place. Zirconium Dioxide coating which also comes under ceramic coating acts as thermal barrier and coated piston crown improves performance of the engine in comparison to the performance of the engine with normal piston.

## IV. EXPERIMENTAL SET UP

The engine utilized for the test is Kirloskar TV1 Variable Compression Ratio (VCR) Engine and as shown in Figure 1. It is a Single cylinder four stroke, Constant Speed and Water Cooled Diesel Engine. The engine specifications are as mentioned in table 1.



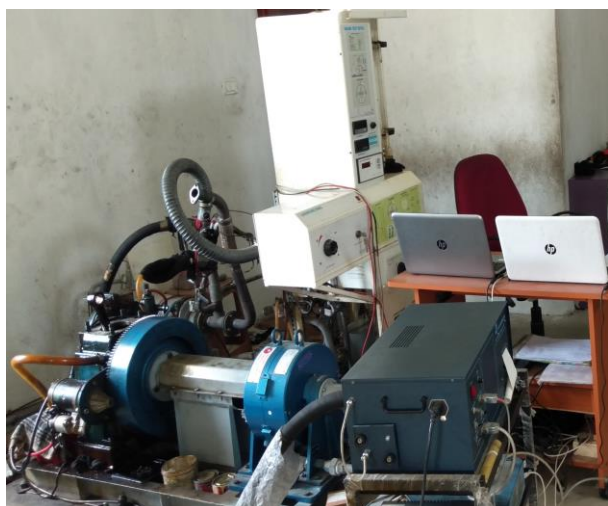


Figure 1: Variable Compression Ratio Engine.

Table 1: Specifications of the Engine.

Sl. No.	Description	Values
1.	Bore dia of Cylinder	87.50 mm
2.	Length of Stroke	110.00 mm
3.	Length of Connecting Rod	234.00 mm
4.	Swept volume	661.45 cm <sup>3</sup>
5.	Compression Ratio	17.50
6.	Power	5.20 kW @ 1500 RPM

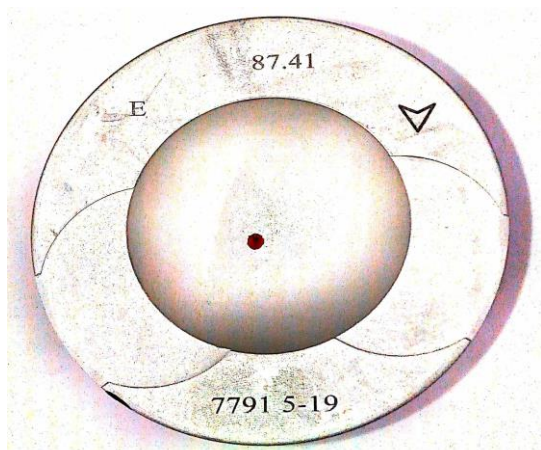


Figure 2. Piston without Coating referred as Normal Piston in this paper.



Figure 3. Piston with 200 micron Zirconium Oxide Coating referred as Coated Piston in this paper.

## V. PROPERTIES OF BIODIESEL AND PURE DIESEL

Table 2: Properties of Biodiesel and Pure Diesel under Standard Conditions.

Sl. No.	Specifications	Microalgae B100 – (Tested in Lab under Standard Conditions)	Diesel D100 (As per ASTM and Indian Standards)
1.	Nature of Sample	Biodiesel – B100	Diesel - D100
2.	Kinematic Viscosity @ 40°C in cSt (centistokes)	4.07	2 - 4.5
3.	Flash Point in °C	108	> 35
4.	Fire Point in °C	119	210
5.	Gross Calorific Value in KJ/kg	39321	46000
6.	Density in Kg/m <sup>3</sup>	896	820 – 860

The crown of the piston coated with zirconium oxide is used for the experiments for combustion and emission characteristics. The blend B20 of algae oil is used as fuel in the VCR engine and the corresponding parameters are compared with parameters obtained with pure diesel D100 as fuel with coated piston and normal piston separately.

## VI. RESULTS AND DISCUSSIONS – COMBUSTION CHARACTERISTICS

### A. Brake Power

The heat generated in the engine is converted into useful work. Almost one third of the amount of heat generated is utilized to produce useful power and remaining two third is lost.

Table 3: Experimental Results – BP in kW.

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	0.02	0.03	0.02
25	1.3	1.32	1.32
50	2.55	2.57	2.58
75	3.73	3.76	3.76
100	4.92	4.94	4.96

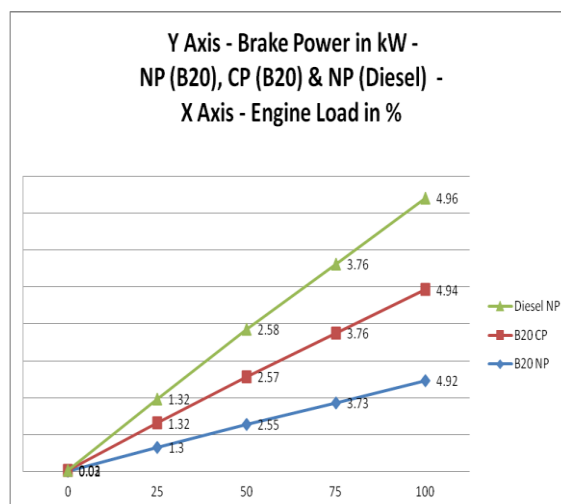


Figure 4: Engine Load in % vs Brake Power in kW.

## Discussion:

**Table: 4 – BP - Comparison – B20 with NP and CP in % with D100+NP.**

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
0.00	50.00
-1.52	0.00
-1.16	-0.39
-0.80	0.00
-0.81	-0.40
+ Increase, - Decrease	

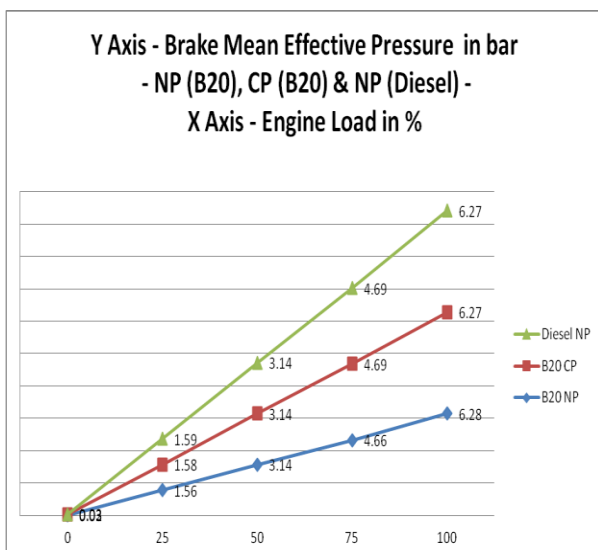
The performance data obtained with B20 with Normal Piston and Coated Piston is compared with that of pure diesel D100 with Normal Piston. Increase in 50 % brake power is observed in case of coated piston at 0% engine load. Overall increase in brake power is observed with coated piston in comparison to normal piston. At 25 % and 75% engine load, 0 % variation is obtained with B20 + Coated Piston and is same as with D100 + Normal Piston whereas it is 1.52% and 0.8 % reduction in brake power with B20 + Normal Piston. At 50% and 100% engine load, 0.39% and 0.4 % reductions in brake power are observed for coated piston whereas 1.16% and 0.81% reductions are for normal piston. Coated piston has performed better.

## B. Brake Mean Effective Pressure (BMEP)

Pressure produced in the combustion chamber is used to produce useful work.

**Table 5: Experimental Results – BMEP in bar.**

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	0.02	0.03	0.03
25	1.56	1.58	1.59
50	3.14	3.14	3.14
75	4.66	4.69	4.69
100	6.28	6.27	6.27



**Figure 5: Engine Load vs Brake Mean Effective Pressure in Bar at 220 Bar Injection Pressure.**

## Discussion:

**Table: 6 – BMEP - Comparison – B20 with NP and CP in % with D100+NP.**

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
-33.33	0.00
-1.89	-0.63
0.00	0.00
-0.64	0.00
0.16	0.00
+ Increase, - Decrease	

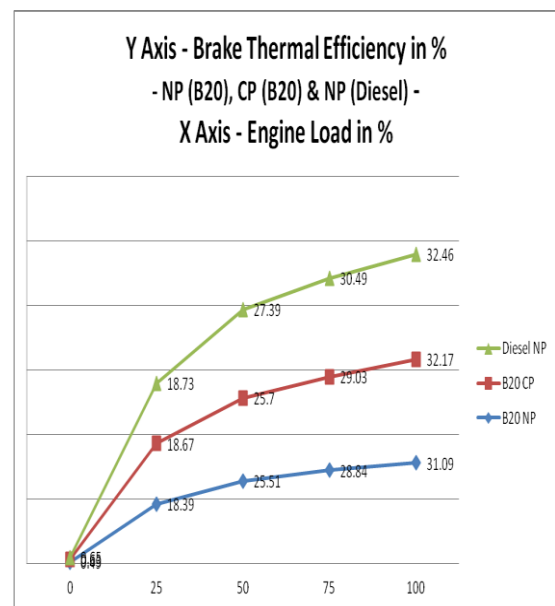
The performance data obtained with B20 with Normal Piston and Coated Piston is compared with that of pure diesel D100 with Normal Piston. At 0%, 50%, 75 % and 100% engine load, 0 % variation is obtained with B20 + Coated Piston whereas 33.33%, 0%, 0.64% and 0.16% reductions respectively with B20 + NP. At 25% engine load, 0.63 % and 1.89% reductions are found with B20 + CP and B20 + NP respectively.

## C. Brake Thermal Efficiency

Effective utilization of heat generated in the cylinder for conversion into power is brake thermal efficiency.

**Table 7: Experimental Results – BTE in %.**

Engine in %	Load	B20 NP	B20 CP	Diesel NP
0		0.49	0.63	0.65
25		18.39	18.67	18.73
50		25.51	25.7	27.39
75		28.84	29.03	30.49
100		31.09	32.17	32.46



**Figure 6: Engine Load vs Brake Thermal Efficiency.**



## Discussion:

**Table: 8 – BTE - Comparison – B20 with NP and CP in % with D100+NP.**

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
-24.62	-3.08
-1.82	-0.32
-6.86	-6.17
-5.41	-4.79
-4.22	-0.89
+ Increase, - Decrease	

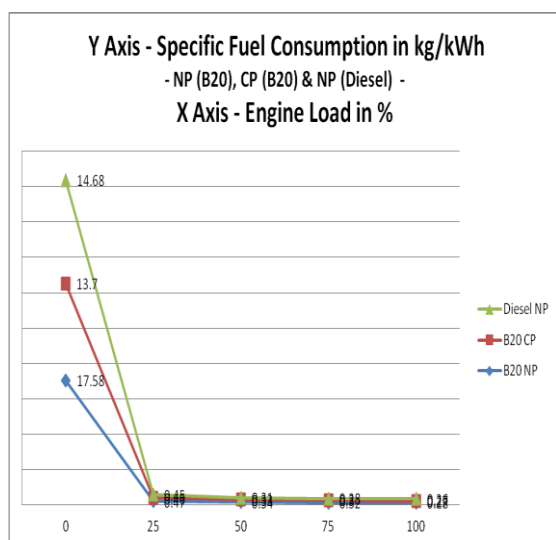
The performance data obtained with B20 with Normal Piston and Coated Piston is compared with that of pure diesel D100 with Normal Piston. At all engine loads, variations are observed and is maximum variation 6.17% is at 50% engine load. But in comparison to B20 + NP, performance with coated piston is better.

## D. Specific Fuel Consumption (SFC)

Fuel consumed per hour per unit power developed is SFC. It should be low at all engine loads.

**Table 9: Experimental Results – SFC in kg/kWh.**

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	17.58	13.7	14.68
25	0.47	0.46	0.45
50	0.34	0.33	0.31
75	0.32	0.3	0.28
100	0.28	0.27	0.26



**Figure 7: Engine Load vs SFC in kg/kWh.**

## Discussion:

**Table: 10 – SFC - Comparison – B20 with NP and CP in % with D100+NP.**

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
19.75	-6.68
4.44	2.22
9.68	6.45
14.29	7.14
7.69	3.85
+ Increase, - Decrease	

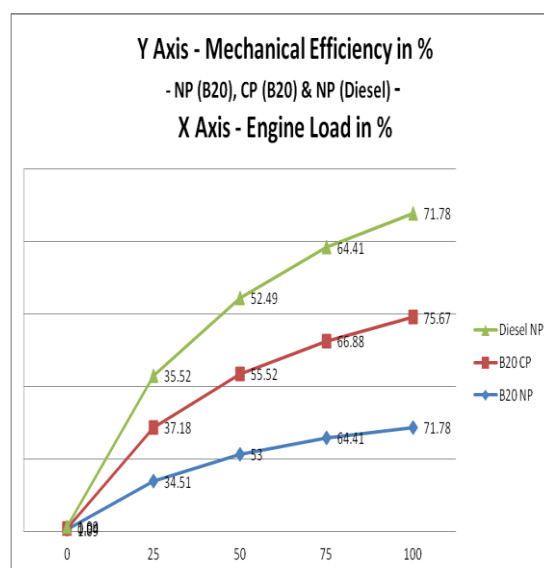
Increase in SFCs is found at all engine loads with respect to B20+CP and are much lower than B20+NP. At 0% engine load, reduction of 6.68% SFC is found in comparison to D100+NP.

## E. Mechanical Efficiency

Conversion of engine power into useful work by all mechanical components of the engine represents mechanical efficiency.

**Table 11: Experimental Results – ME in %.**

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	1.09	0.94	1.09
25	34.51	37.18	35.52
50	53	55.52	52.49
75	64.41	66.88	64.41
100	71.78	75.67	71.78



**Figure 8: Engine Load vs Mechanical Efficiency in %.**

## Discussion:

**Table: 12 – Mechanical Thermal Efficiency - Comparison – B20 with NP and CP in % with D100+NP.**

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
0.00	-13.76
-2.84	4.67
0.97	5.77
0.00	3.83
0.00	5.42
+ Increase, - Decrease	

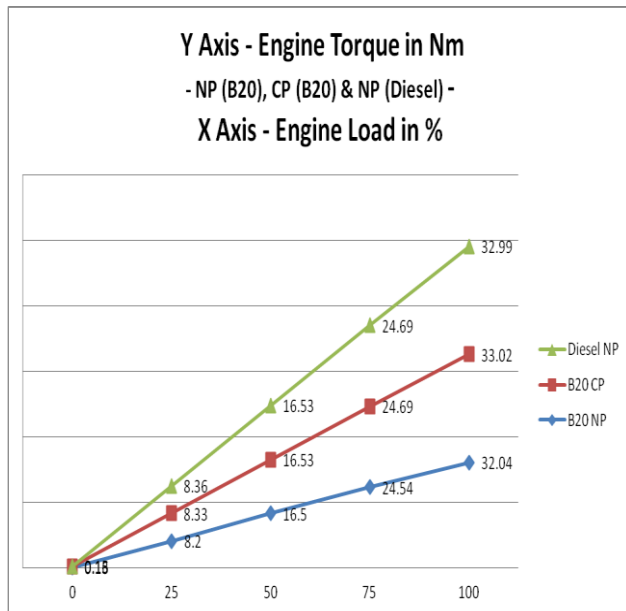
Though almost no variation is found with respect to B20+NP at 0%, 75% and 100% engine load, 13.67% reduction, 3.83% and 5.42% increase respectively observed in performance with B20+CP. At 50% engine load, 5.77% increase is found with B20+CP.

## F. Engine Torque

Engine torque represents the energy used for conversion into useful work and it represents power and turning moment of the engine.

**Table 13: Experimental Results – Engine Torque in Nm.**

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	0.13	0.16	0.15
25	8.2	8.33	8.36
50	16.5	16.53	16.53
75	24.54	24.69	24.69
100	32.04	33.02	32.99



**Figure 9: Engine Load vs Engine Torque in Nm.**

### Discussion:

**Table: 14 – Engine Torque - Comparison – B20 with NP and CP in % with D100+NP.**

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
-13.33	6.67
-1.91	-0.36
-0.18	0.00
-0.61	0.00
-2.88	0.09
+ Increase, - Decrease	

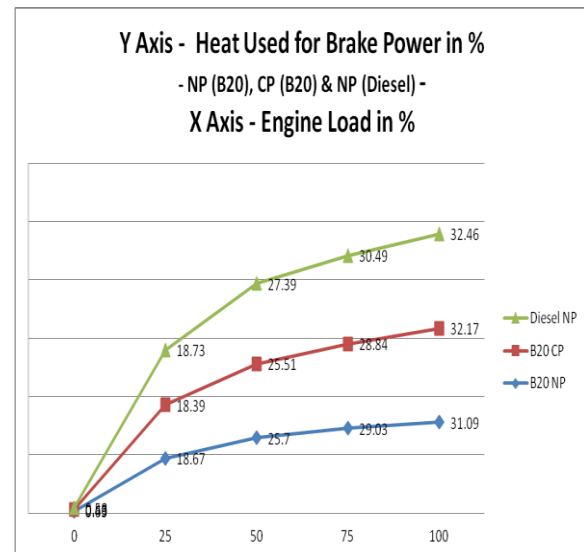
With respect to B20+CP, 6.67% and 0.09% increase in engine torque is observed at 0% and 100% load respectively. At 50% and 75% load, no variation is found and is same as D100+NP. With respect to B20+NP, reduction in engine torque is found at all engine loads.

## G. Heat Used for Generating Power

The heat produced in the engine is not used completely for conversion to useful work. It is experimentally found that only one third of the heat produced is actually converted into useful power. Two third of the heat produced is lost. Technocrats are doing research for reducing the loss to very minimum without polluting the environment.

**Table 15: Experimental Results – Heat Used for BP in %.**

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	0.63	0.49	0.58
25	18.67	18.39	18.73
50	25.7	25.51	27.39
75	29.03	28.84	30.49
100	31.09	32.17	32.46



**Figure 10: Engine Load vs Heat Used for Brake Power in %.**

### Discussion:

**Table: 16 – Engine Torque - Comparison – B20 with NP and CP in % with D100+NP.**

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
8.62	-15.52
-0.32	-1.82
-6.17	-6.86
-4.79	-5.41
-4.22	-0.89
+ Increase, - Decrease	

With respect to B20+CP and in comparison to D100+NP, less amount of heat is utilized at all engine loads to produce power and even brake power produced is lower or similar. With respect to B20+NP at 0% engine load, more heat 8.62% is used whereas 15.52% less heat is utilized for producing similar power with B20+CP.

## VII. RESULTS AND DISCUSSIONS – EMISSION CHARACTERISTICS

The VCR engine is tested for its emission characteristics with B20+CP and B20+NP and the parameters obtained are compared with corresponding characteristics of D100+NP.

### A. CARBON MONOXIDE (CO)

Incomplete combustion in engine is the main cause of emission of carbon monoxide.

Table 17: Experimental Results – CO in %.

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	0.049	0.079	0.029
25	0.044	0.054	0.037
50	0.04	0.062	0.024
75	0.037	0.068	0.031
100	0.185	0.289	0.181

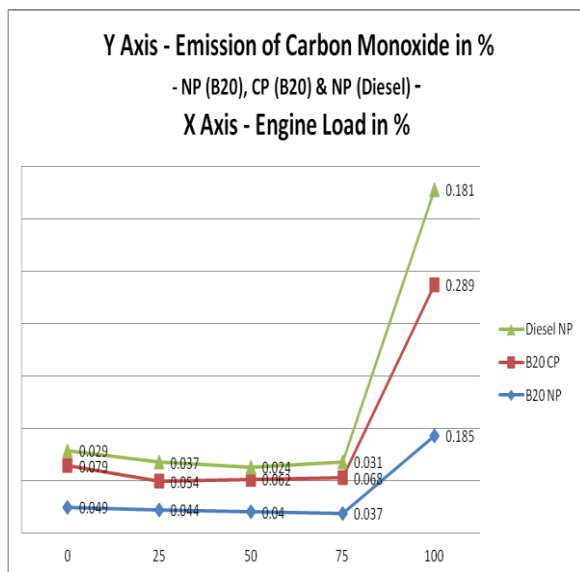


Figure 11: Engine Load vs CO emission in %.

#### Discussion:

Table: 18 – CO - Comparison – B20 with NP and CP in % with D100+NP.

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
68.97	172.41
18.92	45.95
66.67	158.33
19.35	119.35
2.21	59.67
+ Increase, - Decrease	

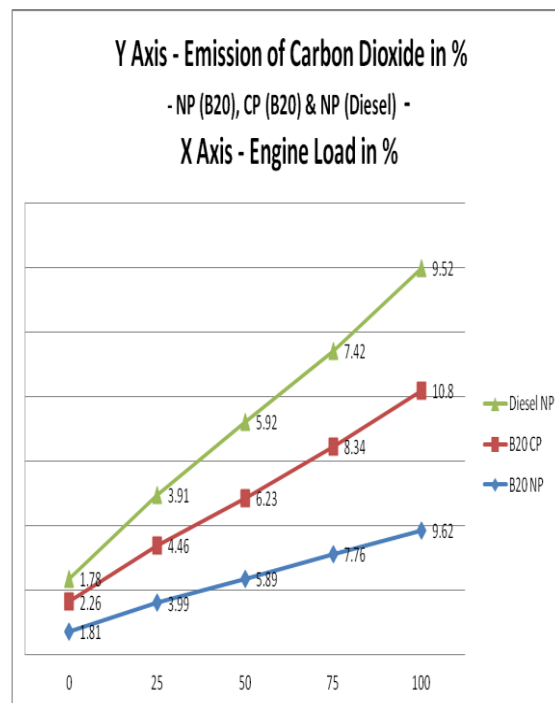
With respect to B20+CP and in comparison to D100+NP, considerable increase in emissions of carbon monoxide is observed at all engine loads. The highest increase of 172.41% is at 0% load. B20 +NP has proved considerably better though it has also resulted in increase in CO emissions but lower than B20+CP and even only 2.21 % increase is at 100% engine load.

#### B. CARBON DIOXIDE (CO<sub>2</sub>)

The emission of carbon dioxide takes place due to unburned fuel in the cylinder and presence of excess oxygen.

 Table 19: Experimental Results – CO<sub>2</sub> in %.

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	1.81	2.26	1.78
25	3.99	4.46	3.91
50	5.89	6.23	5.92
75	7.76	8.34	7.42
100	9.62	10.8	9.52


 Figure 12: Engine Load vs CO<sub>2</sub> emission in %.

#### Discussion:

Table: 20 – CO - Comparison – B20 with NP and CP in % with D100+NP.

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
1.69	26.97
2.05	14.07
-0.51	5.24
4.58	12.40
1.05	13.45
+ Increase, - Decrease	

With respect to B20+CP, at 50% engine load, 5.24% increase in emission of CO<sub>2</sub> is found whereas in other loads, considerable increase in emission of CO<sub>2</sub> is observed in comparison to D100+NP. B20 +NP has proved considerably better and even 0.51% decrease is found at 50% engine load.

#### C. Hydrocarbons (HC)

Unburned fuel in the cylinder may lead to emission of hydrocarbons in ppm. It causes several health hazards including smog in the atmosphere.

Table 21: Experimental Results – HC in ppm.

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	12	30	6
25	22	24	17
50	28	31	25
75	30	35	34
100	50	59	54

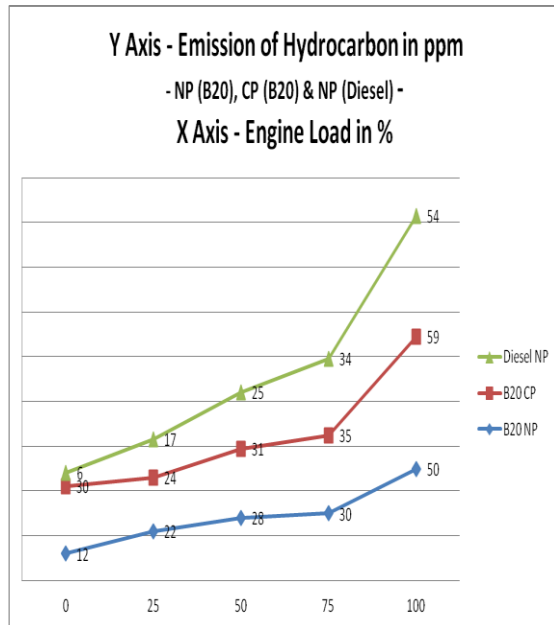


Figure 13: Engine Load vs Hydrocarbons (HC) emission in ppm .

#### Discussion:

Table: 22 – HC - Comparison – B20 with NP and CP in % with D100+NP.

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
100.00	400.00
29.41	41.18
12.00	24.00
-11.76	2.94
-7.41	9.26
+ Increase, - Decrease	

With respect to B20+CP, considerable increase in emissions of HC is found and at 0%, it is even 400% higher. 2.94 % emission is found at 75% engine load. For B20 +NP, results are somewhat better and even reduced emissions of 11.76% and 7.41% are observed at 75% and 100% engine load respectively.

#### D. Oxides of Nitrogen (NO<sub>x</sub>)

Emission of oxides of Nitrogen (NO<sub>x</sub>) takes place in an engine due to high temperature in the cylinder which makes nitrogen to get disassociated from air and combines with oxygen. The oxides of nitrogen are responsible for several health hazards including acid rain in the atmosphere.

Table 23: Experimental Results – NO<sub>x</sub> in ppm.

Engine Load in %	B20 NP	B20 CP	Diesel NP
0	67	131	94
25	458	593	462
50	833	967	849
75	1184	1387	1203
100	1394	1500	1421

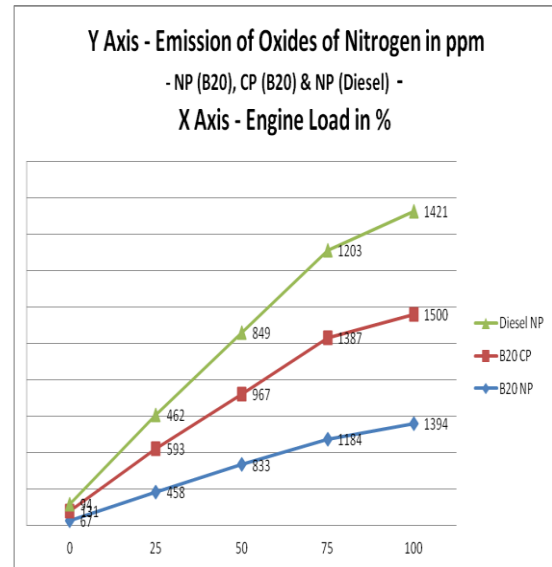


Figure 14: Engine Load vs Oxides of Nitrogen in ppm.

#### Discussion:

Table: 24 – NO<sub>x</sub>- Comparison – B20 with NP and CP in % with D100+NP.

B20 NP vs D100 NP (in %)	B20 CP vs D100 NP (in %)
-28.72	39.36
-0.87	28.35
-1.88	13.90
-1.58	15.30
-1.90	5.56
+ Increase, - Decrease	

With respect to B20+CP, considerable increase in emissions of NO<sub>x</sub> is found at all engine loads. Somewhat better at 100% engine load in which only 5.56% increase is observed. For B20 +NP, results are better and reduced emissions of NO<sub>x</sub> are found at all engine loads.

#### VIII. CONCLUSION AND FUTURE SCOPE

Alternate fuel has become the necessity in future as the availability of fossil fuels in earth for future generation is doubtful. Biomass has become a great source of energy and due to its renewable nature considered as one of the potential product for replacement of fossil fuel. The performance of these biomasses such as algae oil is not similar to the fossil fuel like diesel and even inferior to that which can be improved further by adopting several other methods and also without major modifications in existing engine. In this paper, research work is carried out to find the suitability of B20 algae oil for improving performance using 200µm zirconia coating on piston crown as thermal barrier coating (TBC). The combustion and emission characteristics obtained by using B20 algae oil with normal (NP) and coated (CP) piston separately and compared with the corresponding characteristics of pure diesel D100 used in India. Emission norms have become stricter and even in India using vehicles complying norms as per Bharat VI Standards are only permissible.

B20 +NP has proved better in emission characteristics and at many occasions, the emissions are less than that of D100. Though it is found that the mechanical and combustion performances have improved in case of B20 + CP but simultaneously decrease in emission characteristics have made us to think and adopt some another methods to improve combustion characteristics like using diethyl ether as additive etc. along with TBC in future research work.

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