

Combustion and Emission Characteristics of Methyl Ester Fueled VCR Engine with TBC and EGR



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Abstract — Day by day increase in price of fuel especially in India have created the necessity to develop an alternative fuel having the same characteristics as fossil fuel diesel or petrol have. Simultaneously, rapid decreasing of fossil fuel reserves all over the world has become a major problem for all engineers as almost all industries use petroleum products for producing power. Biodiesel or methyl ester extracted from microalgae is experimented for its combustion and emission characteristics. The same is matched with the corresponding characteristics of fossil fuel diesel. Considerable deviations are found. In order to improve the characteristics of biodiesel, the piston is coated with zirconia and the parameters obtained using VCR engine is compared with the parameters obtained by using exhaust gas recirculation along with thermal barrier coating on piston crown. Considerable reduction in emission of oxides of nitrogen is found.

Key words — Algae, Carbon, EGR, Hydrocarbon, Thermal Barrier, VCR, Zirconia.

I. INTRODUCTION

The world is facing a severe problem of global warming. Emission of green house gases like carbon dioxide by industries and automobiles have become major contributor for this global warming leading to the increase in temperature of earth as a whole. Due to increase in temperature, glaciers are melting at a faster rate and the water level of sea and ocean is increasing day by day. If the same is continuing, one day the land portion of the earth will be submerged and existence of human life will be at risk.

Combustion of fossil fuels in industries and in automobiles is also one of the major sources of emission of pollutants including green house gases. There is a requirement to find an alternate fuel which should be renewable and can reduce even emissions of pollutants. Biodiesel or methyl ester extracted from microalgae has emerged as one of the strong contestant to replace fossil fuel diesel. By using some improved and advanced techniques, the combustion and emission characteristics of biodiesel can be enhanced to an acceptable level and comparable to the corresponding characteristics of fossil fuel diesel. The microalgae consist of almost 50% of carbon and 10% nitrogen and about 2% phosphorous and the remaining 38% is oxygen. The high carbon content makes the microalgae suitable for alternate fuel.

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The microalgae undergoes trans-esterification process along with sodium hydroxide or potassium hydroxide as catalyst with continuous stirring. The methyl ester produced is separated and the settled glycerol is used on cosmetics industries. Thermal barrier coating on piston, cylinder walls, valves etc. is one of the methods to convert more amount of heat into useful work. 200 micron Stabilized Zirconia coating is done on the piston crown. This TBC coated piston is subjected to experimentation for combustion and emission characteristics. The characteristics obtained with coated piston are compared with the corresponding characteristics obtained with 20% exhaust gas recirculation (EGR). EGR is the method to reduce emissions of oxides of nitrogen (NO_x) though some reduction in efficiency takes place in the process. It is working in the concept of pre-mixed charge combustion.

II. THERMAL BARRIER COATING

A highly malleable and ductile zirconium metal is used as thermal barrier coating. The cylinder walls, valves, piston crown etc. is coated with zirconium oxide also known as zirconia. Zirconia is a white crystalline powder and a stabilized coating is preferred. In the experiment performed here, 200 micron stabilized coating is done on piston crown. The piston is used in the variable compression ratio (VCR) engine and combustion and emission characteristics are noted with and without using exhaust gas recirculation.



Figure 1: Coated Piston – Zirconium Oxide – Thermal Barrier Coating.



Figure 2: Normal Piston made of Aluminium Alloy

III. CHEMICAL PROPERTIES OF BIODIESEL AND PURE DIESEL

The properties of biodiesel is measured using standard equipments under standard laboratory conditions where as the properties of pure diesel (D100) is as given by ASTM (American Society for Testing of Materials) standards.

Table 1: Biodiesel and Pure Diesel - Chemical Properties.

1.	Sample - Biodiesel and Diesel (Fossil Fuel)	B100	D100
2.	In Centistokes - Viscosity - Kinematic	4.07	2 - 4.5
3.	In kj/kg - Calorific Value	39321	46000
4.	In 0C - Flash Point	108	> 35
3.	In Kg/m ³ - Density	896	820 – 860
4.	In 0C - Fire Point	119	210

IV. EXHAUST GAS RECIRCULATION (EGR)

This methodology has become popular as it reduces harmful emissions of oxides of nitrogen (NO_x). The exhaust gases are tapped in between from the exhaust pipe and some percentage of exhaust gases are re-circulated to the combustion chamber through induction system for pre-heating and pre-mixing with the charge. This pre-heating and pre-mixing prevents high temperature rise in the combustion temperature and thereby dissociation of nitrogen and oxygen from air is prevented. This results in considerable reduction in emissions of oxides of nitrogen (NO_x). In this paper, 20% exhaust gases are re-circulated for subsequent observation of combustion and emission characteristics.

V. EXPERIMENTAL SET UP

The engine used for the experiments is a Single cylinder four stroke variable compression ratio (VCR) diesel engine. The engine is water Cooled.



Figure 3: Engine used for experiments.

Table 2: Important specifications of the engine used.

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

VI. COMBUSTION

A. Brake Power

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	0.03	0.02	0.02
25	1.32	1.29	1.32
50	2.57	2.55	2.58
75	3.76	3.74	3.76
100	4.94	4.89	4.96

Table 3: Brake power.

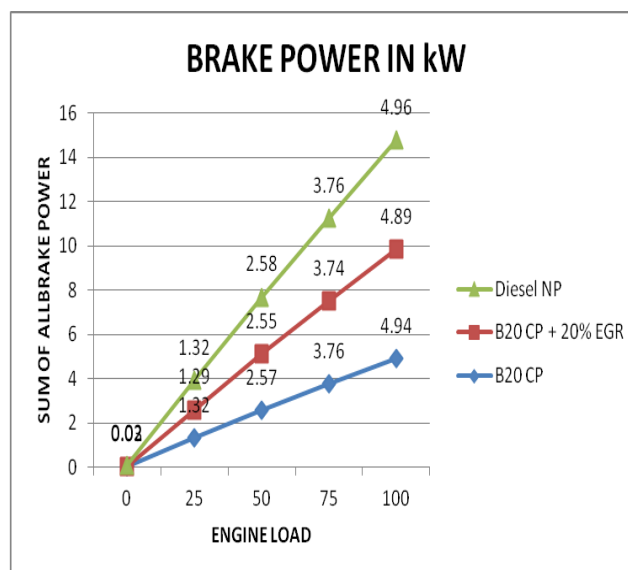


Figure 4: Engine Load - Brake Power.

Observations:

Table: 4 – Changes in Brake power Values.

B20 CP vs D100	B20 CP + 20% EGR vs D100
50.00	0.00
0.00	-2.27
-0.39	-1.16
0.00	-0.53
-0.40	-1.41
+ Increase, - Decrease (in %)	

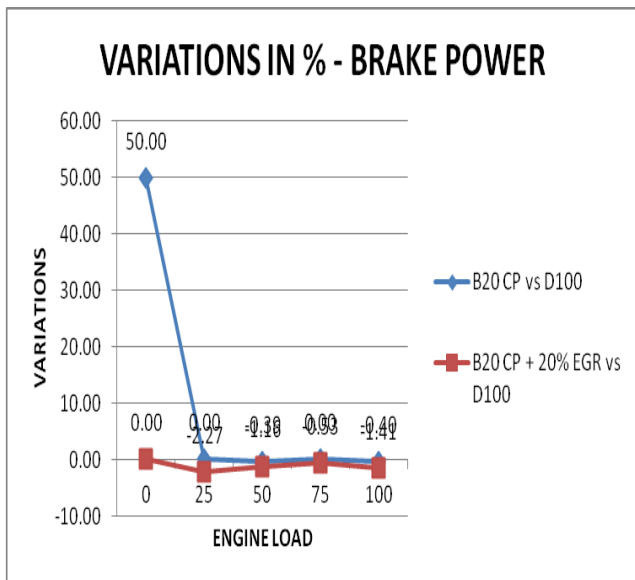


Figure 5: Brake Power - Variations in kW.

Result:

Power produced by the engine is called indicated power whereas actual power utilized for useful work is called brake power. Power which is lost is termed as friction power. The brake power values measured at 0%, 25%, 50%, 75% and 100% engine loads and the corresponding variations for B20CP+EGR and B20CP are shown in tables 3 and 4 respectively. The corresponding graphs are plotted and as shown in figures 4 and 5 respectively.

For B20CP + 20% EGR, there is a decrease in brake power at all loads. This is due to mixing of exhaust gases which lead to improper combustion. 2.27% reduction in brake power has taken place at 25% engine load.

B. Brake Mean Effective Pressure (BMEP)

Table 5: Brake Mean Effective Pressure.

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	0.03	0.02	0.03
25	1.58	1.56	1.59
50	3.14	3.14	3.14
75	4.69	4.66	4.69
100	6.27	6.27	6.27

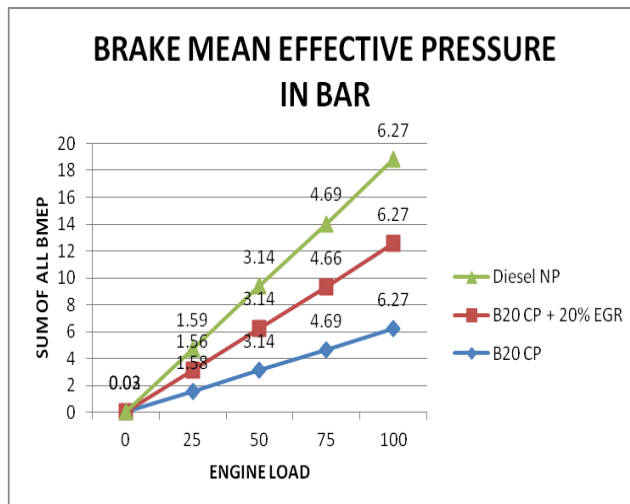


Figure 6: BMEP and engine load.

Observations:

Table: 6: Changes in BMEP values.

B20 CP vs D100	B20 CP + 20% EGR vs D100
0.00	-33.33
-0.63	-1.89
0.00	0.00
0.00	-0.64
0.00	0.00
+ Increase, - Decrease	

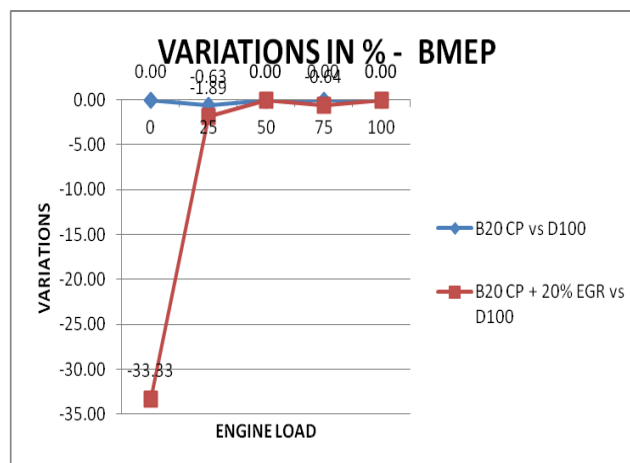


Figure 7: BMEP and engine load.

On combustion of fuel inside the cylinder, high pressure is developed. Total Pressure produced in the engine is called indicated mean effective pressure whereas actual pressure utilized for producing useful torque is called brake mean effective pressure. The brake mean effective pressure values measured at 0%, 25%, 50%, 75% and 100% engine loads and the corresponding variations for B20CP+EGR and B20CP are shown in tables 5 and 6 respectively.

The corresponding graphs are plotted and as shown in figures 6 and 7 respectively.

For B20CP + 20% EGR, there is a decrease in brake mean effective pressure at all loads except at 50% and 100% engine loads. This is due to mixing of exhaust gases consisting of carbon dioxide which lead to improper combustion.

C. Brake Thermal Efficiency (BTE)

Table 7: Brake Thermal Efficiency values in %.

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	0.63	0.38	0.65
25	18.67	16.9	18.73
50	25.7	24.11	27.39
75	29.03	27.64	30.49
100	32.17	29.71	32.46

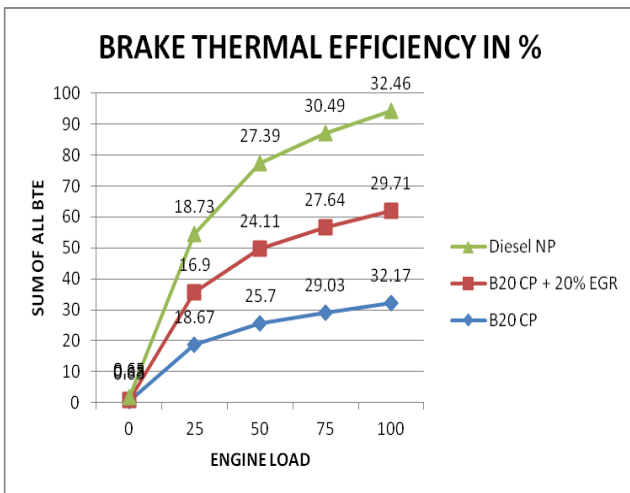


Figure 8: BTE and engine load

Observations:

Table: 8 –BTE - Variations

B20 CP vs D100	B20 CP + 20% EGR vs D100
-3.08	-41.54
-0.32	-9.77
-6.17	-11.98
-4.79	-9.35
-0.89	-8.47
+ Increase, - Decrease	

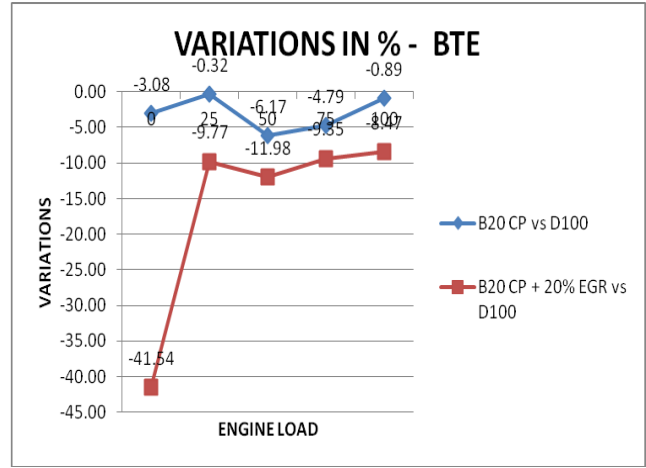


Figure 9: Brake Thermal Efficiency and Engine Load.

Result:

The efficiency of components for producing brake power is termed as brake thermal efficiency. This is also the efficiency of conversion of heat into useful work. The brake thermal efficiency values measured at 0%, 25%, 50%, 75% and 100% engine loads and the corresponding variations for B20CP+EGR and B20CP are shown in tables 7 and 8 respectively. The corresponding graphs are plotted and as shown in figures 8 and 9 respectively.

For B20CP + 20% EGR, there is a considerable reduction in brake thermal efficiency values at all loads and it is high at 0% and 50% engine loads i.e. 41.54% and 11.98%. Exhaust gas recirculation has produced conditions for improper burning of charge in the combustion chamber.

D. Specific Fuel Consumption (SFC)

Table 9: Specific Fuel Consumption in kg/kWh.

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	13.7	22.45	14.68
25	0.46	0.51	0.45
50	0.33	0.36	0.31
75	0.3	0.31	0.28
100	0.27	0.29	0.26

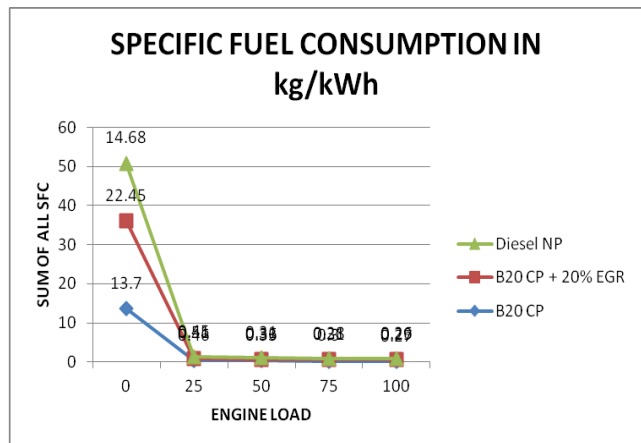


Figure 10: SFC

Observations:

Table: 10 – SFCs.

B20 CP vs D100	B20 CP + 20% EGR vs D100
-6.68	52.93
2.22	13.33
6.45	16.13
7.14	10.71
3.85	11.54
+ Increase, - Decrease	

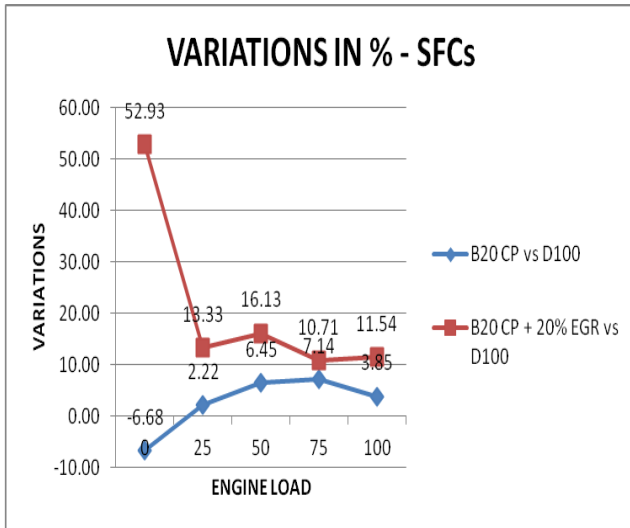


Figure 11: Engine Load - SFC in kg/kWh.

Result:

Fuel consumed by the engine per unit power produced and per unit time is specific fuel consumption which is measured in kg/kWh. The specific fuel consumption values measured at 0%, 25%, 50%, 75% and 100% engine loads and the corresponding variations for B20CP+EGR and B20CP are shown in tables 9 and 10 respectively. The corresponding graphs are plotted and as shown in figures 10 and 11 respectively.

For B20CP + 20% EGR, there is a considerable increase in specific fuel consumption values at all loads and it is high at 0% and 50% engine loads i.e. 52.93% and 16.13%. This increase in SFC is due to improper combustion taking place in the cylinder. As the temperature in the cylinder is less due to EGR, complete combustion is not achieved.

E. Mechanical Efficiency

Table 11: ME in %.

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	0.94	0.79	1.09
25	37.18	37.09	35.52
50	55.52	56.49	52.49
75	66.88	65.99	64.41
100	75.67	75.96	71.78

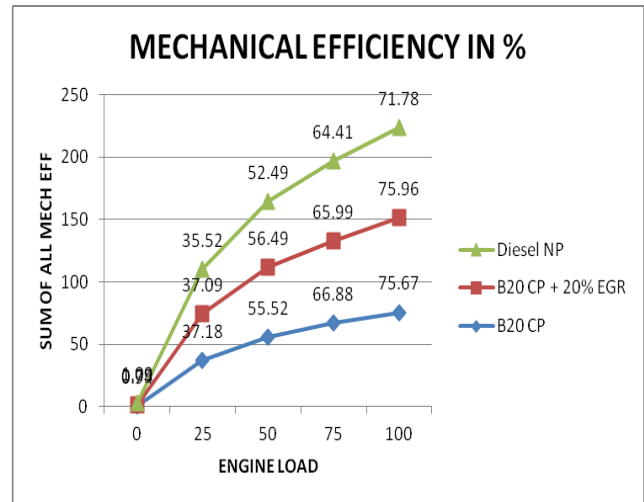


Figure 12: Mechanical Efficiency and Engine Load

Observations:

Table: 12 –Mechanical Efficiency.

B20 CP vs D100	B20 CP + 20% EGR vs D100
-13.76	-27.52
4.67	4.42
5.77	7.62
3.83	2.45
5.42	5.82
+ Increase, - Decrease	

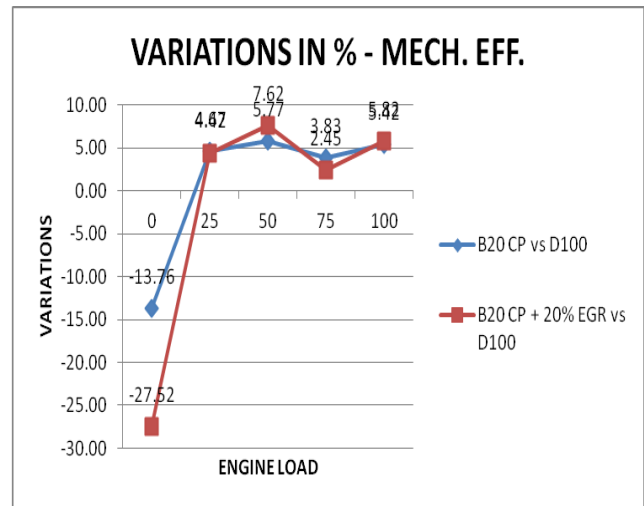


Figure 13: Mechanical Efficiency

Result:

The ratio of brake work done and indicated work done is called mechanical efficiency. It is also the efficient conversion of input heat energy to useful work and is expressed in %. The mechanical efficiency values measured at 0%, 25%, 50%, 75% and 100% engine loads and the corresponding variations for B20CP+EGR and B20CP are shown in tables 12 and 13 respectively. The corresponding graphs are plotted and as shown in figures 13 and 14 respectively.



For B20CP + 20% EGR, there is a considerable decrease in mechanical efficiency at 0% i.e. 27.52% which is 100% decrease in comparison to B20CP. At 25% and 75% engine load also, the decrease in efficiency has taken place. At other engine loads, mechanical efficiency has increased. The incomplete combustion at lower temperature may be the reason for decrease in efficiency.

F. Engine Torque

Table 14: Engine Torque in Nm.

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	0.16	0.1	0.15
25	8.33	8.2	8.36
50	16.53	16.54	16.53
75	24.69	24.54	24.69
100	33.02	33.03	32.99

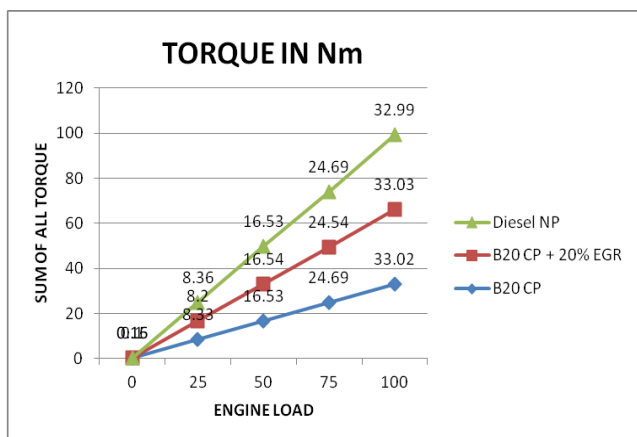


Figure 15: Engine Load - Engine Torque in Nm.

Observations:

Table: 15 – Engine Torque - Comparison – B20 with NP and CP in % with D100+NP.

B20 CP vs D100	B20 CP + 20% EGR vs D100
6.67	-33.33
-0.36	-1.91
0.00	0.06
0.00	-0.61
0.09	0.12
+ Increase, - Decrease	

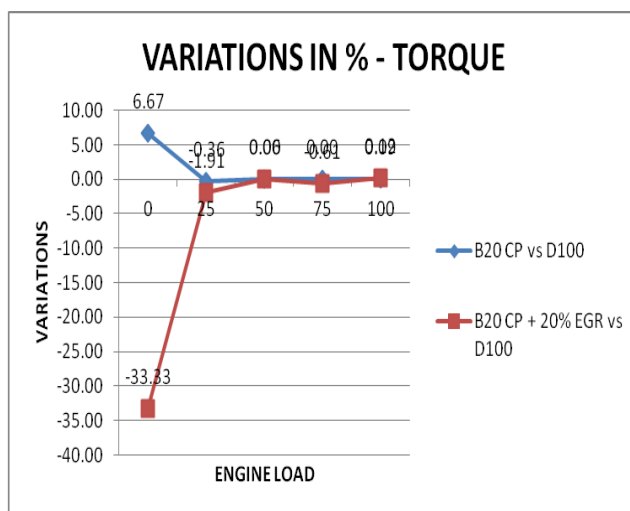


Figure 16: Variations – Engine Torque in Nm.

Result:

The energy produced in the cylinder is converted into useful work and is used for producing torque and is expressed in Nm. The torque values measured at 0%, 25%, 50%, 75% and 100% engine loads and the corresponding variations for B20CP+EGR and B20CP are shown in tables 14 and 15 respectively. The corresponding graphs are plotted and as shown in figures 15 and 16 respectively.

For B20CP + 20% EGR, there is a considerable decrease in torque at 0% i.e. 33.33 %. At 25% and 75% engine load also, the decrease in torque has place. At other engine loads, torque has increased. The incomplete combustion at lower temperature may be the reason for decrease in efficiency and torque.

VII. EMISSION

A. CARBON MONOXIDE (CO)

Table 16: CO in %.

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	0.079	0.051	0.029
25	0.054	0.037	0.037
50	0.062	0.041	0.024
75	0.068	0.109	0.031
100	0.289	2.013	0.181

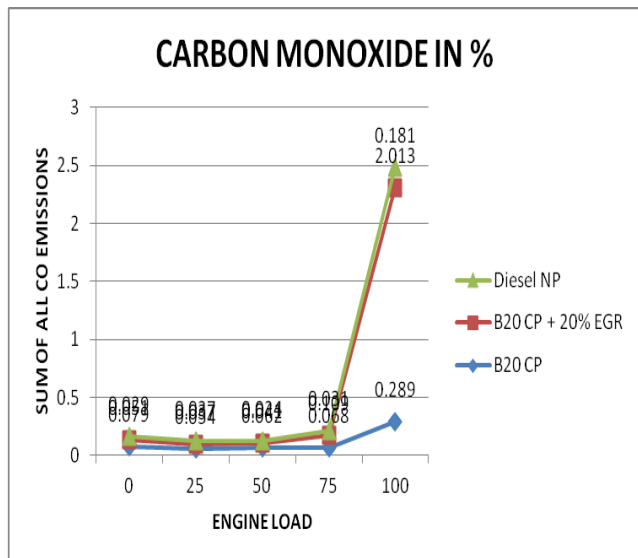


Figure 17: CO Emission in %.

Observations:

Table: 17 – CO emissions

B20 CP vs D100	B20 CP + 20% EGR vs D100
172.41	75.86
45.95	0.00
158.33	70.83
119.35	251.61
59.67	1012.15
+ Increase, - Decrease	

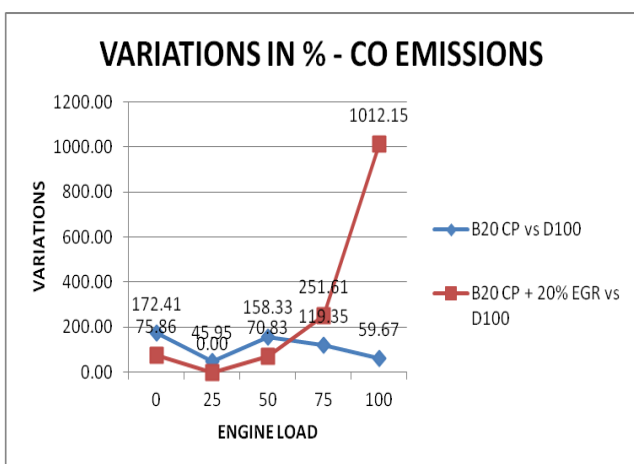


Figure 18: Engine Load - CO emission in %.

Result:

Incomplete combustion of the charge in the cylinder is one of the reasons for emission of carbon monoxide and is expressed in %. At lower loads, 0%, 25%, and 50%, decrease in CO emission is found. At 25% engine load, even 0% emission is observed. But at higher load, increase in emission has taken place. The corresponding variations for

B20CP+EGR and B20CP are shown in tables 16 and 17 respectively. The corresponding graphs are plotted and as shown in figures 17 and 18 respectively.

B. CARBON DIOXIDE (CO2)

Table 18: CO2 in %.

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	2.26	2.22	1.78
25	4.46	4.63	3.91
50	6.23	6.74	5.92
75	8.34	9.37	7.42
100	10.8	11.9	9.52

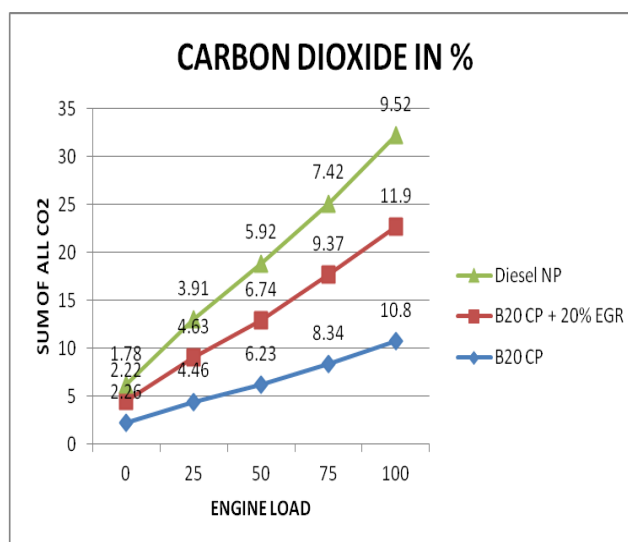


Figure 19: CO2 emission

Observations:

Table: 19 – Variations – CO2.

B20 CP vs D100	B20 CP + 20% EGR vs D100
26.97	24.72
14.07	18.41
5.24	13.85
12.40	26.28
13.45	25.00
+ Increase, - Decrease	

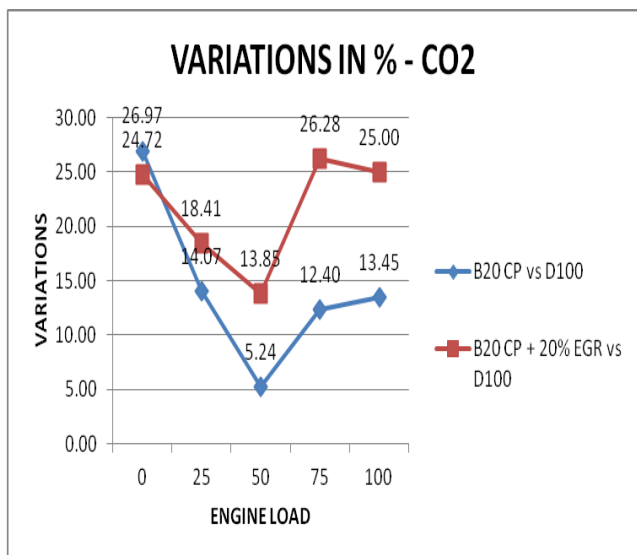


Figure 20: CO2 emission.

Result:

Incomplete combustion of the charge in the cylinder is one of the reasons for emission of carbon dioxide also and is expressed in %. EGR increases CO₂ emissions. Though much harmful effect is not produced on human health due to CO₂ but it is green house gas which has to be reduced as per stringent regulations. The corresponding values for B20CP+EGR and B20CP are shown in tables 18 and 19 respectively. The corresponding graphs are plotted and as shown in figures 19 and 20 respectively.

C. Hydrocarbons (HC)

Table 20: Hydrocarbons in ppm.

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	30	7	6
25	24	11	17
50	31	20	25
75	35	30	34
100	59	75	54

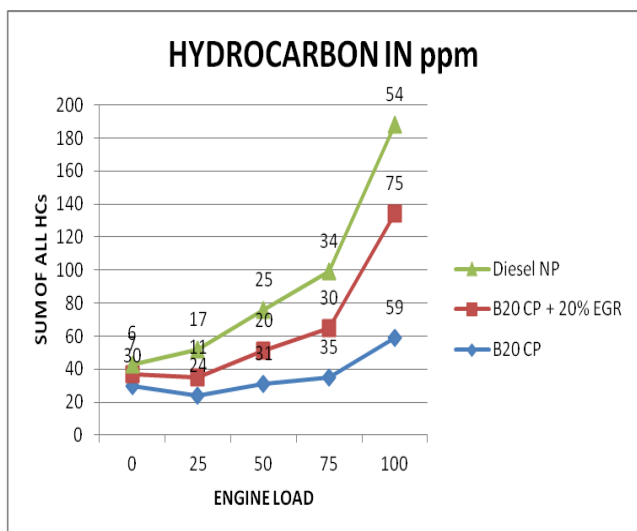


Figure 21: Hydrocarbons (HC) emission in ppm.

Observations:

Table 21: Hydrocarbon

B20 CP vs D100	B20 CP + 20% EGR vs D100
400.00	16.67
41.18	-35.29
24.00	-20.00
2.94	-11.76
9.26	38.89
+ Increase, - Decrease	

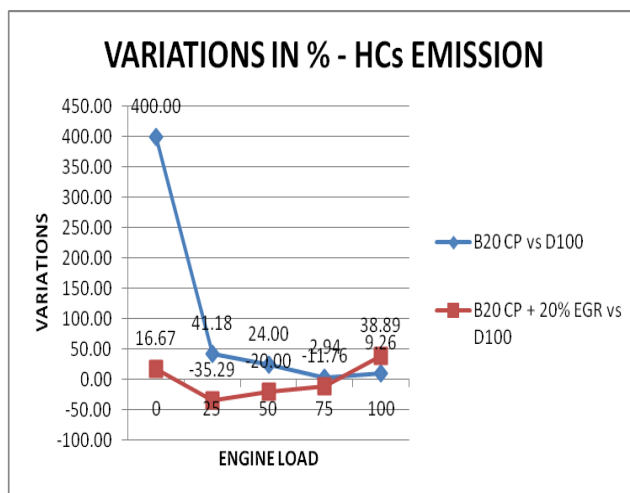


Figure 22: Hydrocarbons (HC) emission in ppm. .

Result:

Incomplete combustion may lead to emission of particulates like hydrocarbons and is expressed in ppm. EGR decreases HC emissions. It creates smog in the atmosphere. Considerable reductions in emissions of HC at all loads except at 100% engine load in comparison of B20CP and that may be due to some irregularities in combustion at higher loads. The corresponding values for B20CP+EGR and B20CP are shown in tables 20 and 21 respectively. The corresponding graphs are plotted and as shown in figures 21 and 22 respectively.

D. Oxides of Nitrogen (NOX)

Table 22: NOX in ppm.

Engine Load in %	B20 CP	B20 CP + 20% EGR	Diesel NP
0	131	100	94
25	593	399	462
50	967	627	849
75	1387	720	1203
100	1500	525	1421

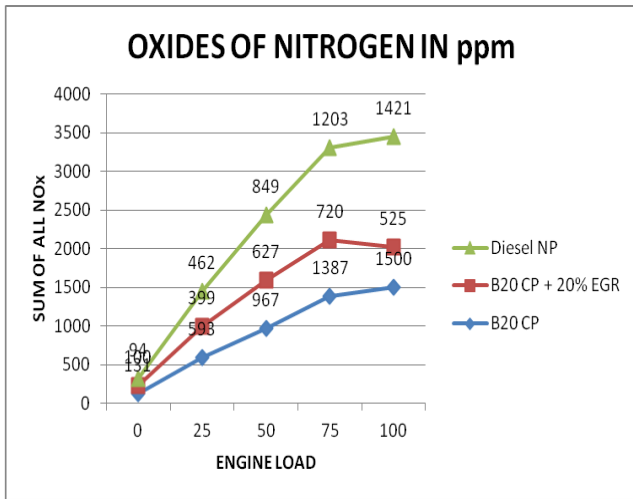


Figure 23: Oxides of Nitrogen in ppm.

Observations:

Table: 23 –NOx emissions

B20 CP vs D100	B20 CP + 20% EGR vs D100
39.36	6.38
28.35	-13.64
13.90	-26.15
15.30	-40.15
5.56	-63.05
+ Increase, - Decrease	

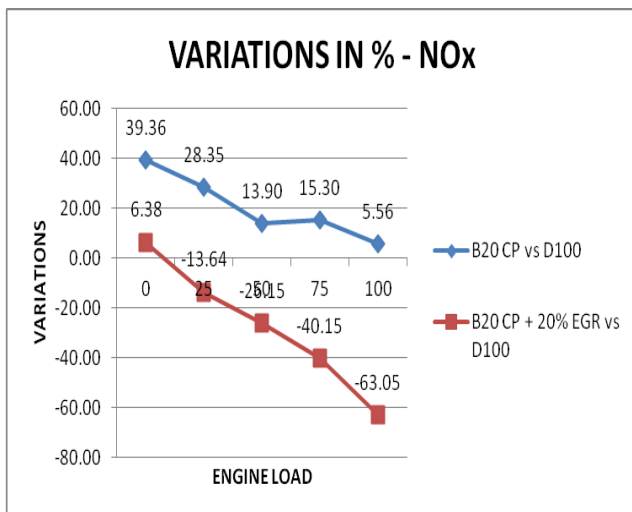


Figure 24: Engine Load - Oxides of Nitrogen in ppm.

Result:

High temperature dissociates nitrogen and oxygen available in air. This high temperature leads to emission of oxides of nitrogen. EGR promotes combustion at lower temperature and thereby emissions of oxides of nitrogen are reduced considerably. The corresponding values for B20CP+EGR and B20CP are shown in tables 22 and 23 respectively. The

corresponding graphs are plotted and as shown in figures 23 and 24 respectively.

VIII. OVERALL RESULT

Sl. No.	Parameter	Performance (Mean)	Possible Reason
1	Brake Power	1.08% decrease with TBC + EGR	Contamination of air fuel mixture with exhaust gas leading to incomplete combustion. Low calorific value of biodiesel. Engine demand is more for fuel and hence high SFC.
2	Brake Mean Effective Pressure	7.17% decrease with TBC + EGR	
3	Brake Thermal Efficiency	16.22% decrease with TBC + EGR	
4	Specific Fuel Consumption	20.93% increase with TBC + EGR	
5	Mechanical Efficiency	1.44% decrease with TBC + EGR	
6	Engine Torque	7.13% decrease with TBC + EGR	
7	Emission of CO	282% increase with TBC + EGR	Contamination of air fuel mixture with exhaust gas leading to incomplete combustion.
8	Emission of CO ₂	21.65% increase with TBC + EGR	
9	Emission of HC	2.3% decrease with TBC + EGR	Theoretically emission of HC should increase with EGR as EGR reduces oxygen content resulting into incomplete combustion. Simultaneously TBC has increased combustion chamber temperature.
10	Emission of NO _x	27.32 % decrease with TBC + EGR	EGR facilitates combustion of charge at lower temperature which may result into improper combustion but simultaneously reduces emission of NO _x considerably.

EGR is considered better for reducing emissions of NO_x and not considered to be very useful for improvement in combustion characteristics.

IX. CONCLUSION AND FUTURE SCOPE

To meet the expectations and demand for an alternative fuel due to shortage of fossil fuels and increase in levels of pollution, engineers are working hard to find a source of renewable energy.



Energy extracted from biomass is a strong competitor and it is found that by using some additives and advanced techniques, the performance of algae oil can be improved further. Simultaneously, the alternative fuels obtained from biomass can be easily processed without causing harm to the atmosphere and health of human beings. The methyl ester produced from chlorella microalgae is used here as a source of biodiesel.

Biodiesel blend B20 is used for experimentation for its suitability. In order to improve its performance, the blend is tested with thermal barrier coated piston in a variable compression engine for its combustion and emission characteristics. Though the performance of the blend improved by using zirconia coated piston but emissions of harmful gases like carbon monoxide, hydrocarbons and oxides of nitrogen did not reduce to a considerable level.

Exhaust Gas Recirculation is one of the methods used preferably for reducing NO_x. 20% EGR is used in this research for reduction of NO_x level to an acceptable level. At lower loads, considerable reductions in the level of emissions of carbon monoxide, hydrocarbons and oxides of nitrogen are achieved but combustion performances have not improved. Due to EGR, incomplete and improper combustion led to decrease in combustion characteristics like brake power, BMEP, brake thermal efficiency, mechanical efficiency, torque etc.

Though coated piston is used for retention of heat in the combustion chamber, but due to EGR, combustion performance did not improve to an acceptable level. Hence, it is concluded from this research that EGR can be used for reducing emissions of nitrogen and other particulates like hydrocarbons. In future, further research can be done to improve performance in combustion characteristics.

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