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Performance and Emission Characteristics of Algae Oil on VCR Diesel Engine

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ABSTRACT

Increased urbanization and increase in population has led to an increased demand for fuels. The result is the prices of fuels are reaching new heights every day. The diesel engines has led to the emission of hazardous gases like Sulphur oxides, nitrogen oxides and carbon monoxide, which can further led to problems like acid rain. These emissions can also affect human health and increase global warming which has led to the need for alternate fuels. Biodiesel is one of the alternatives which are being widely studied and its production from oil seeds is limited by crop land displacement. Production of biodiesel from algae is a promising option. The present work aims to focus on the performance of diesel engine with algae oil as fuel.The properties of algae oil blends with diesel are tested in a variable compression ratio engine (VCR engine) and its performance and emission characteristics are studied.

Keywords: Algae oil; Emission; Diesel engine

INTRODUCTION

The rapid depletion of petroleum based fuels and need for more fuels has resulted in the search for alternative fuels which can serve as the substitute for these petroleum based fuels. Increase in price of these petroleum based fuels and environmental factors caused by them are the other factors which leads to the search of alternative fuels. In this respect biodiesel, which is a well-known renewable energy source have been proposed as a possible solution to meet the increasing energy demand and reduce environmental degradation.

Algae Biofuel

Algae fuel or algal biofuel is an alternative to liquid fossil fuels that uses algae as its source of energy-rich oils. Several companies and government agencies are funding efforts to reduce capital and operating costs and make algae fuel production commercially viable [1-5]. The energy crisis and the world food crisishave ignited interest in algaculture (farming algae) for making biodiesel and other biofuels using land unsuitable for agriculture. Among algal fuels attractive characteristics are that they can be grown with minimal impact on fresh water resources. Algae can be converted into various types of fuel, depending on the technique and part of the cells used. The lipid, or oily part of the algae biomass can be extracted and converted into biodiesel through a process similar to that used for any other vegetable oil or converted in a refinery into “drop-in” replacements for petroleum-based fuels. Alternatively or following lipid extraction, the carbohydrate content of algae can be fermented into bioethanol or butanol fuel (Tables 1 and 2).

Table 1: Algae biodisel vs diesel

Properties	Algae Biodisel	Diesel
Kinematic viscosity in cst at 40°C	3.6	3.1
Calorific value in kj/kg	42923	43200
Density at 150 C in kg/mm^3	850	830
Cetane no.	45	46.4
Flash point (°C)	70	56
Fire point (°C)	83	64

Table 2: Algae- better biodiesel stock

Source	Oil Yield (L/HA*YR)
Soyabean	450
Camelina	560
Sunflower	955
Rapeseed	1190
Jatropha	1890
Oilpalm	5950
Algae	3800-50800

Advantages of Algae Biodiesel

In the beginning biodiesel are mostly produced from sources like soya bean, Camelina, sunflower, Rapeseed, Jatropha, oil palm etc. The oil yield from those sources is comparatively less when compared to algae and its advantages over edible crop sources are

- Rapid growth rates.
- A high per acre yield (7 to 31 times greater than the next best crop palm oil).
- Certain species of algae can be harvested daily.
- Algae bio-fuel contains no sulphur.
- Algae bio-fuels nontoxic.
- Algae bio-fuel is highly biodegradable.

Esterification

Esterification is the general name for a chemical reaction in which two reactants (typically an alcohol and an acid) form an ester as the reaction product. Esters are common in organic chemistry and biological materials, and often have a characteristic pleasant, fruity odour. This leads to their extensive use in the fragrance and flavour industry. Ester bonds are also found in many polymers.

Need For Esterification:

- The direct use of crude renewable oils in diesel engines is envisage able, but could lead to numerous technical problems.
- For example, their characteristics (high viscosity, high density, difficulty to vaporize in cold conditions) cause deposits in the combustion chamber, with a risk of fouling and an increase in most emissions.
- These drawbacks can be mitigated, but not without some modifications of the diesel engine.
- To overcome all these inconveniences, the transformation of microalgae lipids in corresponding esters is essential**.**

EXPERIMENTAL SECTION

Experimental Program

Experimental Measurements

The engine exhaust emissions like hydrocarbon, carbon monoxide, oxides of nitrogen and smoke were measured using appropriate instruments [Figure 1].

HC, CO measurements:

Hydrocarbon and carbon monoxide were measured using five gas analyzer. The instrument consists of a probe which is inserted into the exhaust pipe. The emission levels were displayed on a LCD window.

Figure 1: Experimental program

Measurement of smoke intensity:
Smoke intensity was measured by means of a Bosch Smoke meter. A fixed quantity of the exhaust gas was passed through a fixed filter paper using pneumatically operated sampling pump. The density of the smoke stains on the paper was evaluated optically using a photoelectric unit. The smoke density is given in Bosch Smoke Number (BSN). (Figure 2)

Figure 2: Smoke intensity

Exhaust gas temperature measurement:
The exhaust gas temperature was measured by using a K- Type (Chromel-Alumel) thermocouple.

Cylinder peak pressure measurement:
A high speed digital data acquisition system in conjunction with a piezo-electric transducer was used for the measurement of cylinder pressure history.

Features of VCR Engine

- Changing CR without stopping the engine
- Study of Open ECU
- Performance optimization with ECU programming
- Diesel and Petrol operation
- Diesel injection point advancement

- Electric starting arrangement
- PΘ-PV plots, IP, IMEP, FP indication
- Combustion analysis

Readings from VCR Engine (Figures 3-7)
Base reading of pure diesel in VCR engine:

TORQUE (N-M)	Time for 5cc (S)	Brake power (KW)	BMEP (bar)	Total fuel consumption (kg/KW-hr)	Specific fuel consumption (kg/Kw-hr)	Brake thermal efficiency D100 (%)	Specific energy consumption (KJ/KW-hr)	Indicated power (KW)	IMEP (bar)	Indicated thermal Efficiency (%)	Mechanical Efficiency (%)
0	32.1	0	0	0.448598	∞	0	∞'	2.3	2.754491	42.72569	0
8	27.6	1.5072	1.826909	0.541304	0.359146	23.20321	15515.09	3.8072	4.559521	58.61151	39.58815
16	18.31	3.0144	3.653818	0.815948	0.270683	30.78629	11693.52	5.3144	6.364551	54.27636	56.72136
24	13.26	4.5216	5.480727	1.126697	0.249181	33.44289	10764.62	6.8216	8.169581	50.45427	66.28357
32	8.12	6.0288	7.307636	1.839901	0.305185	27.30581	13184.01	8.3288	9.974611	37.72303	72.38498

Figure 3: Base reading of pure diesel in VCR engine

Readings of A-20 blend (Algae-20) in VCR engine:

TORQUE (N-M)	Time for 5cc (S)	Brake power (KW)	BMEP (bar)	Total fuel consumption (kg/KW-hr)	Specific fuel consumption (kg/Kw-hr)	Brake thermal efficiency D100 (%)	Specific energy consumption (KJ/KW-hr)	Indicated power (KW)	IMEP (bar)	Indicated thermal Efficiency (%)	Mechanical Efficiency (%)
0	32	0	0	0.45	∞	0	∞'	2.3	2.754491	42.59259	0
8	27.1	1.5072	1.826909	0.551292	0.365772	22.78286	15801.35	3.8072	4.559521	57.54971	39.58815
16	17.9	3.0144	3.653818	0.834637	0.276883	30.09692	11961.36	5.3144	6.364551	53.061	56.72136
24	12.7	4.5216	5.480727	1.176378	0.260169	32.03052	11239.28	6.8216	8.169581	48.32347	66.28357
32	8.1	6.0288	7.307636	1.844444	0.305939	27.23855	13216.56	8.3288	9.974611	37.63012	72.38498

Figure 4: Readings of A-20 blend (Algae-20) in VCR engine

Readings of A-40 blend (Algae-40) in VCR engine:

TORQUE (N-M)	Time for 5cc (S)	Brake power (KW)	BMEP (bar)	Total fuel consumption (kg/KW-hr)	Specific fuel consumption (kg/Kw-hr)	Brake thermal efficiency D 100 (%)	Specific energy consumption (KJ/KW-hr)	Indicated power (KW)	IMEP (bar)	Indicated thermal Efficiency (%)	Mechanical Efficiency (%)
0	30.3	0	0	0.475248	∞	0	∞'	2.3	2.754491	40.32986	0
8	27.7	1.5072	1.826909	0.53935	0.357849	23.28728	15459.08	3.8072	4.559521	58.82387	39.58815
16	17.01	3.0144	3.653818	0.878307	0.29137	28.60048	12587.2	5.3144	6.364551	50.42277	56.72136
24	12.2	4.5216	5.480727	1.22459	0.270831	30.76948	11699.91	6.8216	8.169581	46.42097	66.28357
32	8.02	6.0288	7.307636	1.862843	0.308991	26.96953	13348.4	8.3288	9.974611	37.25846	72.38498

Figure 4: Readings of A-20 blend (Algae-20) in VCR engine

Readings of A-60 blend (Algae-60) in VCR engine:

TORQUE (N-M)	Time for 5cc (S)	Brake power (KW)	BMEP (bar)	Total fuel consumption (kg/KW-hr)	Specific fuel consumption (kg/Kw-hr)	Brake thermal efficiency D 100 (%)	Specific energy consumption (KJ/KW-hr)	Indicated power (KW)	IMEP (bar)	Indicated thermal Efficiency (%)	Mechanical Efficiency (%)
0	29.1	0	0	0.494845	∞	0	∞'	2.3	2.754491	38.73264	0
8	26.6	1.5072	1.826909	0.561654	0.372647	22.36252	16098.37	3.8072	4.559521	56.48791	39.58815
16	16.9	3.0144	3.653818	0.884024	0.293267	28.41553	12669.13	5.3144	6.364551	50.0967	56.72136
24	11.7	4.5216	5.480727	1.276923	0.282405	29.50843	12199.9	6.8216	8.169581	44.51847	66.28357
32	8.01	6.0288	7.307636	1.865169	0.309376	26.9359	13365.06	8.3288	9.974611	37.21201	72.38498

Figure 5: Readings of A-60 blend (Algae-60) in VCR Engine

Readings of A-80 blend (Algae-80) in VCR engine:

TORQUE (N-M)	Time for 5cc (S)	Brake power (KW)	BMEP (bar)	Total fuel consumption (kg/ KW-hr)	Specific fuel consumption (kg/ Kw-hr)	Brake thermal efficiency D 100 (%)	Specific energy consumption (KJ/KW-hr)	Indicated power (KW)	IMEP (bar)	Indicated thermal Efficiency (%)	Mechanical Efficiency (%)
0	29	0	0	0.496552	∞	0	∞'	2.3	2.754491	38.59954	0
8	25.5	1.5072	1.826909	0.585882	0.388722	21.43775	16792.81	3.8072	4.559521	54.15194	39.58815
16	16.5	3.0144	3.653818	0.905455	0.300376	27.47297	12976.29	5.3144	6.364551	48.91098	56.72136
24	11.1	4.5216	5.480727	1.345946	0.29767	27.99518	12859.36	6.8216	8.169581	42.235498	66.28357
32	7.45	6.0288	7.307636	2.005369	0.332632	25.05274	14369.68	8.3288	9.974611	34.61042	72.38498

Figure 6: Readings of A-80 blend (Algae-80) in VCR engine

Readings of pure biodiesel A-100 (Algae-100) in VCR engine:

TORQUE (N-M)	Time for 5cc (S)	Brake power (KW)	BMEP (bar)	Total fuel consumption (kg/ KW-hr)	Specific fuel consumption (kg/ Kw-hr)	Brake thermal efficiency D 100 (%)	Specific energy consumption (KJ/KW-hr)	Indicated power (KW)	IMEP (bar)	Indicated thermal Efficiency (%)	Mechanical Efficiency (%)
0	27	0	0	0.533333	∞	0	∞'	2.3	2.754491	35.9375	0
8	22.2	1.5072	1.826909	0.672973	0.446505	18.66345	19289.03	3.8072	4.559521	47.14404	39.58815
16	12.1	3.0144	3.653818	1.234711	0.409604	20.34485	17694.9	5.3144	6.364551	35.86805	56.72136
24	10.1	4.5216	5.480727	1.479208	0.327143	25.47309	14132.56	6.8216	8.169581	38.43048	66.28357
32	6	6.0288	7.307636	2.49	0.413018	20.17671	17842.36	8.3288	9.974611	27.87416	72.38498

Figure 7: Readings of pure biodiesel A-100 (Algae-100) in VCR engine

Emission Readings (Figures 8-11)
Nitrogen oxides (NO_X) emission readings:

BRAKE POWER (KW)	BASE (ppm)	A-20 (ppm)	A-40 (ppm)	A-60 (ppm)	A-80 (ppm)	A-100 (ppm)
0	81	95	98.2	99.1	99.4	99.9
1.5072	240	249	252.1	252.9	253.6	259.3
3.0144	400	422	433	439	444	489
4.5216	750	759	765	777	789	851
6.0288	889	902	915	926	955	978

Figure 8: Nitrogen oxides (NOX) emission readings

Carbon dioxide (CO_2) emission readings:

BRAKE POWER (KW)	BASE (% vol)	A-20 (% vol)	A-40 (% vol)	A-60 (% vol)	A-80 (% vol)	A-100 (% vol)
0	0.74	0.77	0.78	0.81	0.812	0.833
1.5072	1.19	1.21	1.25	1.27	1.28	1.31
3.0144	1.23	1.29	1.32	1.33	1.34	1.37
4.5216	1.35	1.39	1.4	1.42	1.44	1.49
6.0288	1.52	1.6	1.67	1.68	1.72	1.75

Figure 9: Carbon dioxide (CO2) emission readings

Corbon monoxide (CO) emission readings:

BRAKE POWER (KW)	BASE (% vol)	A-20 (% vol)	A-40 (% vol)	A-60 (% vol)	A-80 (% vol)	A-100 (% vol)
0	0.13	0.08	0.08	0.1	0.11	0.11
1.5072	0.14	0.06	0.07	0.09	0.1	0.1
3.0144	0.19	0.12	0.15	0.18	0.185	0.187
4.5216	0.25	0.1	0.2	0.22	0.24	0.28
6.0288	0.26	0.11	0.18	0.21	0.23	0.252

Figure 10: Corbon monoxide (CO) emission readings

Hydro carbon (HC) emission readings:

BRAKE POWER (KW)	BASE (ppm)	B-20 (ppm)	B-40 (ppm)	B-60 (ppm)	B-80 (ppm)	B-100 (ppm)
0	40	29.1	29.8	30.5	31.1	32.1
1.5072	41.39	37.1	37.7	38.2	40	40.3
3.0144	47.8	39	39.4	40.1	42.3	43.4
4.5216	45.4	37.8	43.2	44.4	46.3	47.1
6.0288	71.1	61.7	64.4	65.1	68.8	69.5

Figure 11: Hydro carbon (HC) emission readings

RESULTS

Results on Performance Characteristics

Brake thermal efficiency and specific energy consumptions are the two performance characters discussed here.

Brake thermal efficiency:

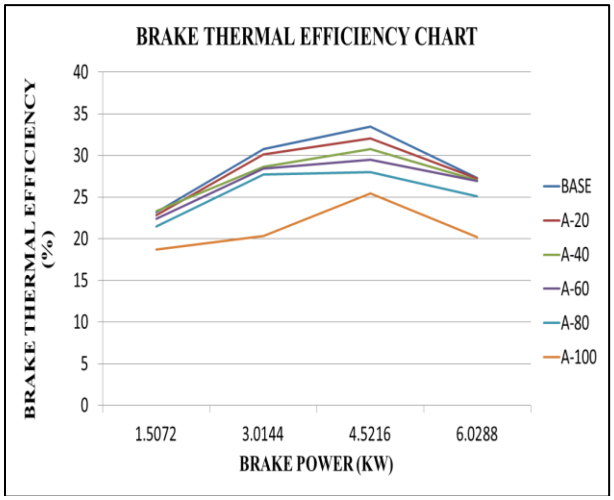

Figure 12: Brake thermal efficiency

The maximum brake thermal efficiency for neat diesel is 33.44%.
For A-20 It is 32.03%, for A-40 it is 30.76%, for A-60 it is 29.50%, for A-80 it is 27.99% and for A-100 it is 25.47% (Figure 12).

Specific energy consumption:

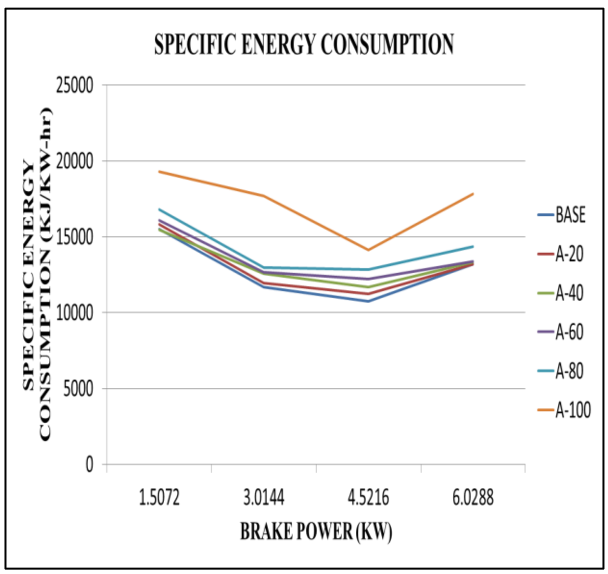

Figure 13: Specific energy consumption

Specific energy consumption for neat diesel at three fourth of the load is 10764.62 KJ/KW-hr.
For diesel blends it starts to increase by 4.4%, 8.68%, 13.33%, 19.45%, and 31.28% for A-20, A-40, A-60, A-80, A-100 respectively (Figure 13).

Results on Emission Characteristics

Nitrogen oxides, carbon dioxide, carbon monoxide and hydro carbon are the emissions discussed here.

NO_X emissions:

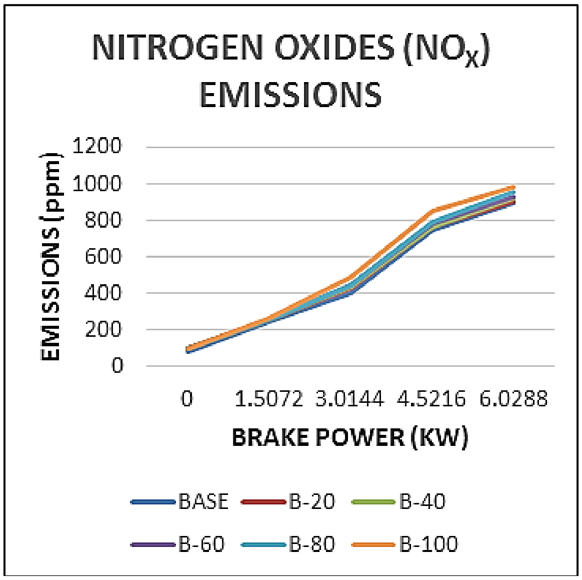

Figure 14: NOX emissions

The NO_X emission for neat diesel at maximum load is 889 ppm and it starts to increase for the biodiesel blends.
The emission increases by 1.46%, 2.92%, 4.16%, 7.42%, 10.01% for A-20, A-40, A-60, A-80, A-100 respectively (Figure 14).

CO emissions:

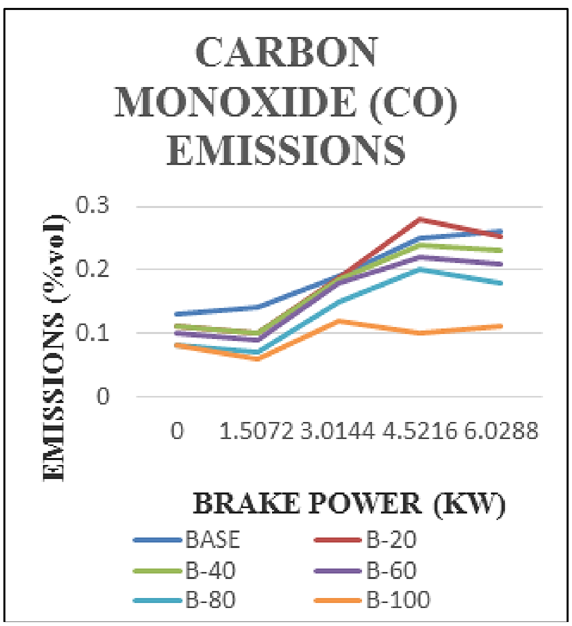

Figure 15: CO emissions

The carbon monoxide emissions for neat diesel at maximum load are 0.26%.
The emissions decrease by 0.252%, 0.23%, 0.21%, 0.18%, 0.11% for A-20, A-40, A-60, A-80, A-100 respectively at maximum load (Figure 15).

CO_2 emissions:

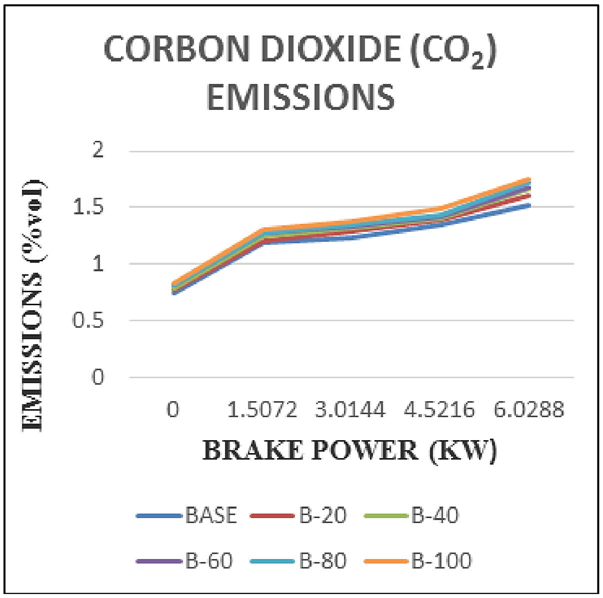

Figure 16; CO2 emissions

The co_2 emission for neat diesel at maximum load is 1.52%.
And for diesel blends it is 1.6%, 1.67%, 1.68%, 1.72%, 1.75% for A-20, A-40, A-60, A-80, A-100 respectively (Figure 16).

Hydro carbon emissions:

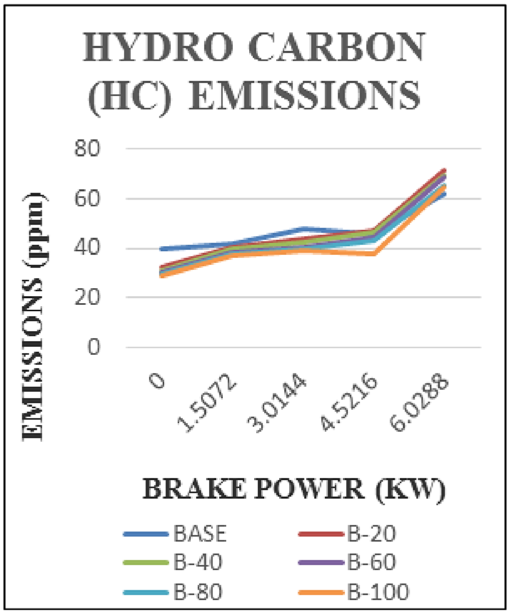

Figure 17: Hydro carbon emissions

The hydro carbon emission for neat diesel at maximum load is 71.1 ppm and it starts to decrease for bio diesel blends. The emission decreases to 61.7 ppm, 64.4 ppm, 65.1 ppm, 68.8 ppm, 69.5 ppm for A-20, A-40, A-60, A-80, A-100 respectively (Figure 17).

Specifications of Test Engine

Make: Kirloskar AV-I
No of cylinder: One
Type of cooling: Water
Ignition: Compression Ignition
Bore: 80 mm
Stroke: 110 mm
Compression ratio: 16.5:1
Speed: 16.6:1
Brake Power: 3.70kW
Brake Horse Power: 5
Fuel oil: H.S. Diesel
SFC: 24.5g/kWh
Lubricating oi: SAE 30/SAE 40 (Room temperature above 45U C)

CONCLUSION

Comparison of Various Performance and Emission Characteristics among Diesel and Various Blends of Biodiesel with Diesel

Various Characteristics	Diesel	A-20	A-40	A-60	A-80	A-100
Brake Thermal Efficiency (%)	33.44	32.03	30.76	29.5	27.99	25.47
Specific Energy Consumption (KJ/KW-hr)	10764.62	11239.28	11699.91	12199.9	12859.36	14132.56
Nitrogen Oxide Emissions (ppm)	889	902	915	926	955	978
Carbon Monoxide Emissions (%vol)	0.26	0.11	0.18	0.21	0.23	0.252
Carbon Dioxide Emissions (%vol)	1.52	1.6	1.67	1.68	1.72	1.75
Hydro Carbon Emissions (ppm)	71.1	61.7	64.4	65.1	68.8	69.5

Among various blends of algae biodiesel tested in VCR engine Algae-20 has the least exhaust characteristics and better performance characteristics. Hence 20% methyl ester of algae oil and 80% of diesel blend at standard temperature of 27 ^{0} C and standard compression ratio 18:1 gives slightly better performance and reduced emission when compared to other diesel blends.

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