

Combustion of Cotton Seed Oil Derived Fuel by Catalytic Cracking in Diesel Engine

Mr.N. Muthukumaran

Assistant Professor, Department of Mechanical Engineering, Annamalai University, Tamilnadu, India

Abstract - In this study, the biofuel produced from the cotton seed oil through catalytic cracking process. In this process the Lignite Fly Ash (LFA) selected as a catalyst material for cracking process and the cracking process was conducted on a fixed bed catalytic cracking reactor at the temperature range of 450-500°C. By analyzing the LFA through EDS (Energy Dispersive Spectroscopy), it reveals the presence of oxide of aluminium, silicon and iron in it. The morphology and surface texture of fly ash is figured out by using SEM image. The cracked cotton seed oil is subjected to GC-MS (Gas Chromatography – Mass Spectrometry) analysis, which shows the presence of olefins, saturated and unsaturated acids in the cracked oil. The performance and emission characteristics of cracked oil are evaluated with diesel blends in single cylinder, four stroke, water cooled DI diesel engine. The results reveals that the Brake Thermal Efficiency (BTE) at B25 show the closer to neat diesel. The exhaust emission of oxides of nitrogen (NO_x) is decreased with increasing the maximum load for B100 than neat diesel. However, the emission of HC and CO slightly increasing with increasing the percentage of load than the neat diesel.

Keywords: Cotton seed oil, Catalytic cracking, Lignite fly ash and Combustion

1. INTRODUCTION

In the past centuries, the needs of energy consumption are widely fulfilled by the petroleum based fuel. But in the recent time, the energy requirement of the world increasing enormously. The increased use of these fuels has resulted in depletion of resources. So, the fossil fuel could not able to cope with the need of energy requirement. Also the use of petroleum based fuel leads to excessive emission of carbon monoxide, CO_2 , HC, NO_x and oxides of Sulphur, which is greater threat to the environment results in global warning. In this case, the world must have more towards the alternative, renewable, sustainable and efficient energy sources with lesser emission. For that Bio fuel act as a perfect alternate for the conventional energy resource because of its environmental benefits and the fact that it is made from the renewable resources.

Vegetable oil is one of the biological sources to produce bio fuel. The vegetable oil is the renewable resource and also have the higher potential to produce energy which comparable to the diesel fuel. Although it was not acceptable widely because they were costlier than petroleum based fuel. However, interest in bio fuel production due to the increase of petroleum prices and the lack of its availability [1]. Biofuel shows a lesser combustion emission such as CO, HC than

petroleum based fuel. However, the emission of NO_x is slightly higher than the other emission. In order to control NO_x emission several techniques to follow such as change in composition of feed stock, improve the cetane number, retardation of injection timing and exhaust gas recirculation [2]. Some of the vegetable oil such as corn, rapeseed, cotton seed, soyabean, sunflower, peanut, castor, linseed, safflower, sesame, can be were identified in that cotton seed, corn, rapeseed, sesame and soyabean oil considered as a effective replacement fuel for the diesel fuel [3]. The major factor which affect the direct use of vegetable oil as a fuel in diesel engine is its viscosity.

High viscosity affects the operations of fuel injectors and it leads to poor atomization of fuel spray, ring stickening and less accurate of its working [1]. Hence it is essential to reduce the viscosity of vegetable oil. The method used to convert vegetable oil into biofuel where Transesterification, Thermal cracking, Catalytic cracking. Transesterification is one of the traditional method to reduce the viscosity of the oil. The drawback of transesterification is molar ratio of glycerides to alcohol, catalyst, reaction temperature and pressure, reaction time and the contents of FFA and waters in the oil [4]. Catalytic cracking is also a route to produce bio fuel from non-edible vegetable oil. Bio fuel produced through catalytic cracking from non-edible oil surpass than other bio fuels to their sustainable & non-polluting nature and non-Sulphur containing compounds. The outcome of the catalytic cracking biofuel has higher amount of alkanes and aromatics which are more effective petroleum range hydrocarbon [5]. This method requires low operating temperature less than 450°C and low catalyst to oil ratio and its burns cleanly [6]. The temperature of the reaction had impact on its yield of liquid hydrocarbon and its properties and also the supply of non-condensable gas [7]. The type of catalyst used in the methods were microporous and mesoporous catalyst. Microporous catalyst such as zeolites and mesoporous catalyst such as SBA-15 and MCM-41 have better selectivity cracking catalyst [8]. The catalyst improves 98% of the biofuel production and also affects the performance, combustion and emission characteristics [9]. The biofuel obtained from catalytic process contains various hydrocarbons segments such as aliphatic, aromatic, oxygenated aromatic and polar compounds which act as a reasonable substitute for transport fuel [10]. The efficiency of biodiesel is marginally lower than that of regular diesel fuel, owing to their low calorific value of the blends. The another reason for efficiency diminution of biofuel muddle are volatility, higher viscosity and higher density [11].

This research is based on Production of biofuel by catalytic cracking of cotton seed oil with lignite fly ash as a catalyst. The cottonseed biofuel is blended with diesel at various proportions and investigate its performance, combustion and emission characteristics of Direct Injection (DI) diesel engine.

2. MATERIALS AND METHODS

2.1. Cotton Seed Oil

The cotton seed is obtained from the seed of cotton plant. The cotton seed belongs to the species of Gossypium from the family Malvaceae. It is one of crop abundantly found in the tropical and subtropic regions of more than 80 countries. In India, the major cotton growing states are Gujarat, Punjab, Haryana, Rajasthan, Madhya Pradesh, Maharashtra, Andra Pradesh, Karnataka and Tamil Nadu. Cotton were primarily cultivated for its fiber as a raw material for textile industries. The following composition of free fatty acid in the cotton seed oil is shown in the table 1 [12].

Table 1. Composition of raw cottonseed oil [12]

S.No	Properties	Weights (%)
1.	Myristic (14:0)	0.5-2.5
2.	Palmitic (16:0)	17-29
3.	Stearic (18:0)	1-4
4.	Oleic (18:1)	13-44
5.	Linoleic (18:2)	33-58
6.	Linoleic (18:3)	0.1-2.1

2.2. Lignite fly Ash

In this study, lignite fly ash is used as a catalyst for the cracking process. It is collected from Neyveli Lignite Corporation or Neyveli Thermal Power plant. It is a waste by-product from industries and power plants. Fly ash particles are spherical in shape and in size of (0.5 to 100µm) and are highly heterogeneous and contains glassy particles such as mullite, quartz and iron oxides [13]. Fly ash produced during the burning of coal, the fly ash collected from the electrostatic precipitator or bag houses. By analyzing through EDS, it figure out the presence of Aluminum, Silicon, Iron in the fly ash, so it acts as a better catalyst for catalytic process [14]. The following chemical composition of lignite fly ash is shown in the table 2 [15].

Table 2. Properties of lignite fly ash [15]

Components	Composition(wt%)
SiO ₂	52.66
Al ₂ O ₃	23.37
Fe ₂ O ₃	8.72
CaO	5.75
MgO	2.75
SO ₃	2.40
TiO ₂	0.08
MnO	0.06
ZnO	0.04
Na ₂ O	0.01
K ₂ O	0.01
PbO	0.01
Weight loss(at 800°C)	3.53

2.3 Catalytic Cracking Process

Catalytic cracking is defined as the conversion process of one substance into another in the presence of heat with the help of catalyst in the absence of air molecules. Which results the cleavage of long chain compounds into small chain compounds.

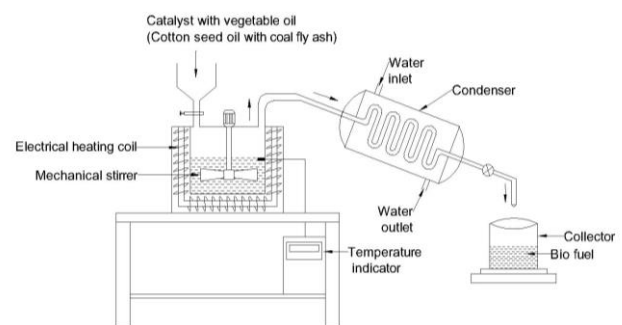


Fig. 1: Catalytic cracking reactor

The experimental setup of catalytic cracking reactor was shown in Fig.1. The catalytic cracking of cottonseed oil is carried out in the catalytic cracking reactor which is heated upto a temperature of 450 to 500°C with the help of an electrical coil and the temperature is measured using a calibrated thermocouple fitted inside the reactor. The cottonseed oil is added with lignite flyash to make it as slurry by using mechanical stirrer and fed into the reactor. While heating the reactor to its optimum temperature, with the help of catalyst the catalytic cracking reaction takes place.

During the catalytic cracking reaction the hydrocarbon vapour delivered from the slurry and it passes to the condenser where it gets cooled. After the condensation process the liquid hydrocarbon is collected in the fuel collector tank.

2.4. Composition and properties of catalytically cracked Cotton seed oil

GC-MS spectrometer were collected with the retention time and the contents of compounds in biofuel. Each component shows separate peaks which identify the formation of olefins, saturated and unsaturated acids in the cracked oil as shown in Table 3.

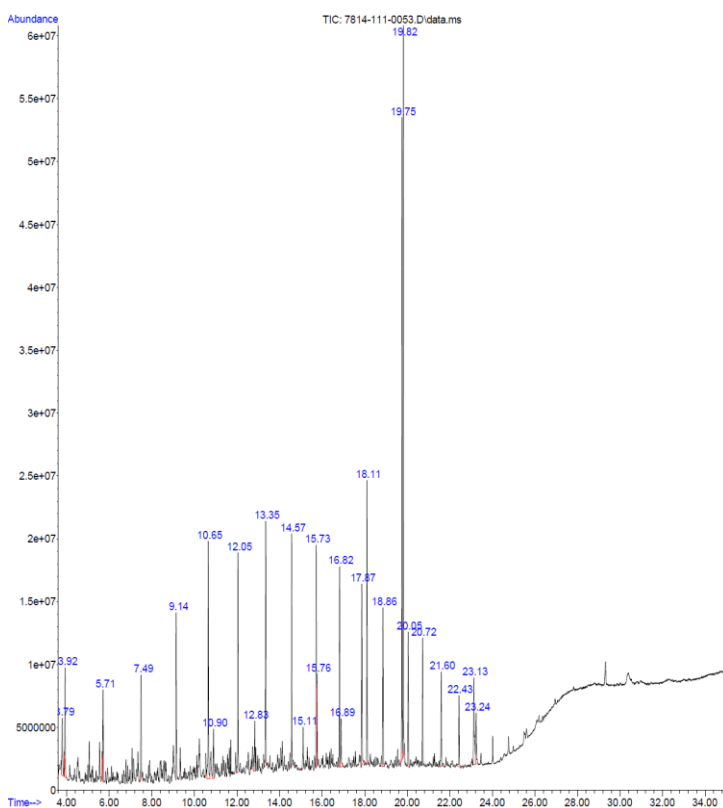


Fig.2. GC-MS analysis for catalytic cracking biofuel

2.5. Elemental composition of LFA

By analyzing through EDS, the elemental compositions such as oxides of aluminium, silicon and iron occupy the major portion of lignite fly ash nearly about 90% and other compositions such as Ca, K, Ti captured less than 10% of its weights. SEM image of lignite fly ash shows the morphology and surface texture of the fly ash which indicates the presence of hydrocarbon.

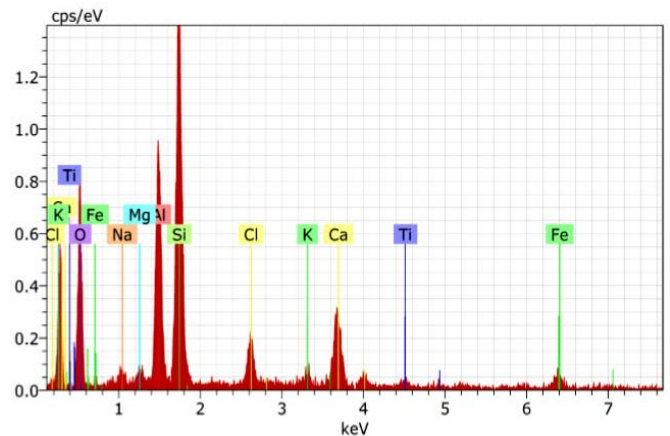


Fig.3. EDS analysis of LFA

Table 4. Properties of LFA

Element	Atomic Number	Series	unn.C [wt.%]	Norm.C [wt.%]	Atom.C [at.%]	Error (1Sigma) [wt.%]
O	8	K-series	42.78	35.22	36.31	8.86
C	6	K-series	41.84	34.46	47.31	9.89
Si	14	K-series	14.01	11.53	6.77	0.70
Al	13	K-series	9.93	8.17	5.00	0.58
Ca	20	K-series	5.74	4.72	1.94	0.28
Cl	17	K-series	2.18	1.80	0.84	0.15
Fe	26	K-series	1.80	1.48	0.44	0.17
Na	11	K-series	0.88	0.72	0.52	0.15
K	19	K-series	0.86	0.71	0.30	0.10
Ti	22	K-series	0.80	0.66	0.23	0.10
Mg	12	K-series	0.63	0.52	0.35	0.11
Total			121.44	100.00	100.00	

3. Experimental Setup and Arrangement

An experiment is executed on Kirloskar TV-1, single cylinder, four stroke, air-cooled diesel engine. The graded power of the engine is 4.4 kW at 1500 rpm. The diesel engine is operated at a standard injection pressure of 200 bar pressure and constant speed of 1500 rpm. The fuel flow rate is measured on volume basis using a burette and a stop watch. K-type thermocouple and a digital display are employed to note the exhaust gas temperature. The Hartridge smoke meter is utilised for the measurement of smoke density. The temperature of the exhaust gas is measured using K-Type thermocouples. Exhaust emissions viz., Hydrocarbon, carbon monoxide, NO_x are measured by using AVL Di – gas analyzer. Combustion parameters like cylinder pressure and heat release rate are measured by using AVL Combustion Analyzers.

Table 3. Chemical characterization of Cotton seed oil

Peak No.	Time(min)	Component
1	5.133	Decane, Tetradecane
2	6.751	3,5- Undecane, 4-Heptafluorobutyryloxyhexadecane
3	6.977	2,3,5- Undecane
4	8.392	1- Dodecane, Cyclododecane
5	8.534	Dodecane, Decane, 3,6- dimethyl
6	9.593	Hexadecane, 2,6,11,15- tetramethyl
7	10.039	Tridecane, undecane, 4,8- dimethyl
8	11.061	Dodecane, 2,6,10- trimethyl
9	12.060	Cyclopentane, 1- hexyl-3-methyl
10	12.720	Pentadecane, Hexadecane
11	13.368	n-Nonylcyclohexane, Cyclopentadecane
12	13.809	7-Hexadecane, 5-Octadecane
13	14.421	Tritetracontane, Tetratetracontane
14	14.950	8-Heptadecane, 3-heptadecane
15	15.051	Hexacosane, Tetradecane,2,6,10-trimethyl
16	16.116	Pentadecane, Hexacosane
17	17.156	Heptadecane, 8-methyl
18	17.418	Pentadecanoic acid, 14-methyl, methyl ester
19	18.143	Eicosane
20	19.106	11-Octadecenoic acid, methyl ester
21	19.980	Octadecane, 2-chloro, Nonadecane,9-methyl
22	20.825	Nonadecane, 9-methyl, Tritetracontane
23	21.443	9-Tricosane, 1-Nonadecene
24	21.503	9-Tricosane, 1-Heneicosanol
25	22.436	Heneicosane, Eicosane
26	22.888	E-11-Hexadecen-1-ol
27	23.060	9-Tricosene
28	28.269	Palmitic acid vinyl ester

Table 5. Specification of the test engine

Make	KIRLOSKAR TV-1
Type	Vertical, Water cooled, Four stroke
No. of cylinder	1
Bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5:1
Speed	1500 rpm
Dynamometer	Eddy current
Maximum power	5.2 KW
Injection timing	23° before TDC
Injection Pressure	220 kgf/cm ²

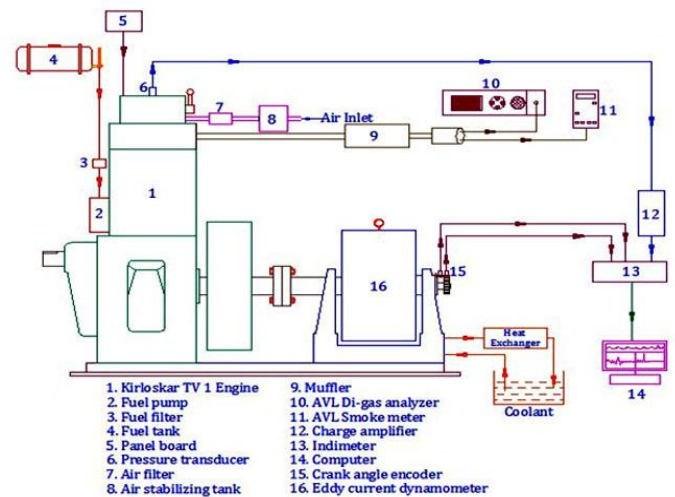


Fig.4. Schematic diagram of the engine experimental setup

4. Results & Discussion

4.1. Brake Thermal Efficiency

The variation of BTE with brake power for various blends are shown in fig.5. In general brake power is directly proportional to the brake thermal efficiency, because the heat loss is minimized at peak load thus it increases the brake thermal efficiency. At maximum loads the BTE of the blends slightly lower than the diesel. This is due to the presence of oxygen content in the biofuel and also the rate of combustion is low due to the higher viscosity and lower heating value of the biofuel than the neat diesel. The BTE of

B25 blends show the closer efficiency to neat diesel than other blends.

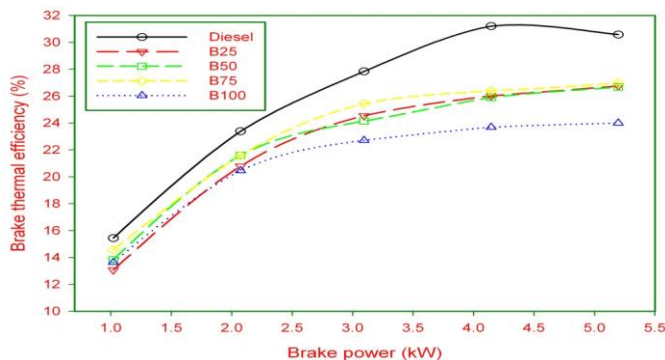


Fig.5. Brake Power with respect to BTE

4.2. Smoke Density

The variation of smoke density with respect to brake power for diesel and biofuel blend is shown in fig.6. From the graph it is observed that the smoke opacity is increased with increasing load for biofuel blends. The smoke opacity of biofuel blends is lower than diesel at initial load. But in peak load all the blends except B25 shows higher smoke density than diesel. This is due to the incomplete combustion of biofuel blend caused by poor vaporization, air-fuel mixing and higher viscosity of biofuel.

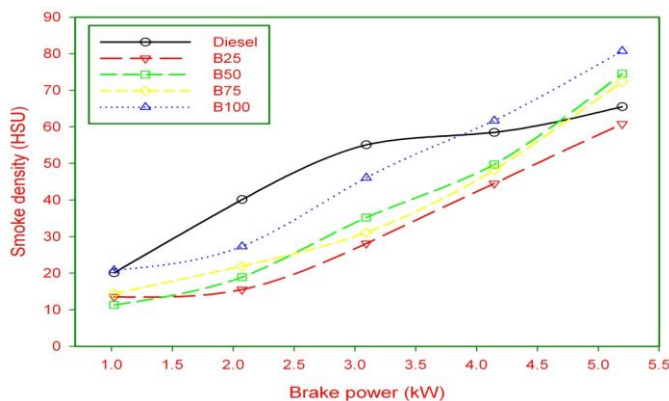


Fig.6. Brake Power with respect to Smoke Density

4.3. Oxides of Nitrogen

The variation of oxides of nitrogen with respect to brake power for diesel and biofuel blend are shown in fig.7. It is observed that various blends of biofuel shows lower NO_x emission with increasing biofuel blends when compared to diesel fuel. The results show the lower NO_x emission occurs due to lesser burning rate of biofuel blends, lesser atomization and lower calculated cetane index. The NO_x emission of B100 is reduced about 610ppm than diesel fuel of about 1130ppm.

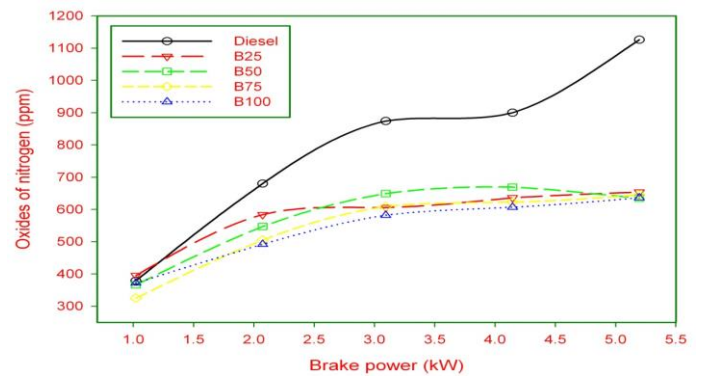


Fig.7. Brake Power with respect to NO_x

4.4. Hydrocarbon

The variation of hydrocarbon with respect to brake power as shown in fig.8. The HC emission indicates the act of the incomplete combustion in the combustion chamber. The HC emissions increased with increasing load, this is due to engine operating condition, properties of fuel and spray formation were the major factors influencing the hydrocarbon emissions. The B25 show the higher HC emission when compared to that of diesel fuel at initial load. However, the hydrocarbon emission of B100 is predominantly higher in comparison with diesel at peak load.

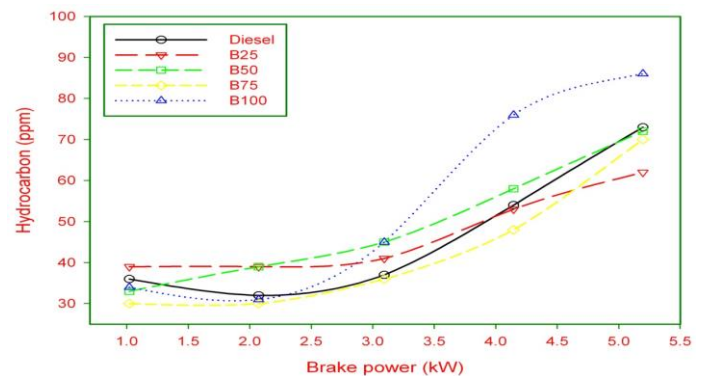


Fig.8. Brake Power with respect to HC

4.5 Carbon Monoxide

The fig.9 shows the variation of CO emission with respect to brake power. Generally, the CO emission is affected by air-fuel equivalence ratio, fuel type, combustion chamber design and start of injection timing. It is observed that CO emission of all biofuel blends consistently increases with increasing the biofuel blends. The low injection pressure and atomization rate affects primary combustion process and subsequently generate high concentration of CO emission with proportion of cotton seed biofuel blend increasing. The CO emission of B25 almost nearer to sole fuel upto part load condition. The blend B100 shows higher CO

emission than other blends however, diesel fuel show the lowest CO emission

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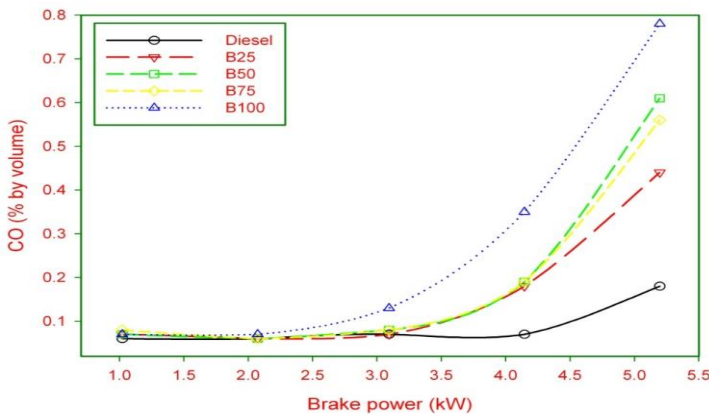


Fig.9. Brake Power with respect to CO

5. Conclusions

The biofuel has been produced by catalytic cracking process using lignite fly ash as a catalyst. The conclusion made from the properties of cotton seed biofuel and lignite fly ash are

- i) The cotton seed biofuel will be directly used as a fuel in an unmodified diesel engine.
- ii) The EDS and SEM analysis reveals the presence of aluminium oxide, silicon, iron and hydrocarbon in lignite fly ash which acts as a perfect catalyst for the catalytic cracking process.
- iii) The GC-MS shows the presence of olefins, saturated and unsaturated acids in cotton seed biofuel.

The performance and emission characteristics of cotton seed biofuel and diesel blends were evaluated in single cylinder, four stroke, water cooled diesel engine. From this experiment the following conclusion were made,

- i) The BTE of B25 blend show closer to neat diesel than other blends.
- ii) At peak load condition the emission of HC and CO were increased with increasing the biofuel blends. However, the diesel fuel produces lower emission.
- iii) The No_x emission show the reducing trend of biofuel blends and B100 produce lower No_x emission than neat diesel.

From the above conclusion, B25 blend can be used as a better alternative for the diesel engine application.

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