Journal of Fundamentals of Renewable Energy and Applications

Senthil and Silambarasan J Fundam Renewable Energy Appl 2015, 5:3
DOI: 10.4172/2090-4541.1000159

Research article Open Access

Performance and Emission Characteristics of Annona-Ethanol Blend Fuelled with Diesel Engine

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Abstract

In this present work aims at evaluate the performance and emission characteristics of a diesel engine fueled with annona-ethanol blend as a fuel. A single cylinder water-cooled four stroke diesel engine was used. The ethanol is blended with Annona Methyl Ester (AME) in the proportions of 60-40, 55-45, 50-50, 45-55. The performance and emission characteristics of annona-ethanol blends are evaluated by operating the engine at different load conditions. The performance parameters such as Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE) and Exhaust Gas Temperature (EGT) were evaluated. Further, the exhaust emissions such as oxides of nitrogen (NOx) unburned hydrocarbon (HC), carbon monoxide (CO) and smoke were measure. It is found that annona-ethanol blend (A-E-50-50) showed slight increase in brake thermal efficiency with the reduction of exhaust gas temperature. Further, it is found that the slight reduction in NOx emission and smoke emission. It is also found that reduction in HC and CO emission was achieved. Hence, it is concluded that A-E 50-50 can be used as alternate fuel for DI diesel engine without any major modification.

Keywords: Annona methyl ester; Ethanol; Performance; Emission; Diesel engine

Introduction

Diesel engines are commonly used as prime movers in the transportation, industrial and agricultural sectors because of their high brake thermal efficiency and reliability. The increasing industrialization and motorization of the world has led to a steep rise in the demand of petroleum based fuels. Petroleum based fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of the world. Therefore, those countries not having these resources are facing energy/foreign exchange crisis, mainly due to the import of crude petroleum. Hence, it is necessary to look for alternative fuels which can be produced from resources available locally within the country such as alcohol, biodiesel, vegetable oils etc. Ethanol is also an attractive alternative fuel because it is a renewable bio-based resource and it is oxygenated, thereby providing the potential to reduce particulate emissions in compression ignition engines.

Renewable fuels like biodiesel and ethanol are carbon neutral fuels, which will remove carbon dioxide from the atmosphere while they grow and emits the same amount CO_2 while combustion.

Studies on the use of ethanol in diesel engines have been continuing since the 1970s. The initial investigation was focused on reduction of the smoke and particle levels in the exhaust. Ethanol addition to diesel fuel results in different physical-chemical changes in diesel fuel properties, particularly reductions in cetane number, viscosity and heating value. Therefore, different techniques involving alcohol-diesel dual fuel operation have been developed to make diesel engine technology compatible with the properties of ethanol based fuels.

The vegetable oil, animal fats, used frying oil, waste cooking oil and edible oils such as soybean, sunflower, canola, palm and non-edible oils such as *Jatropha curcas*, *Pongamia pinnata*, *Madhuca indica*, *Ficus elastica*, *Nicotina tabacum*, and *Calophyllu inophyllumm* can be used as an alternate fuel for diesel [1]. The performance, emission and combustion of DI diesel engine using rapeseed oil and its blends of 5%, 20%, 70% and standard fuel. He has reported that the biodiesel produces lower smoke emission and higher brake, specific fuel consumption compare to the diesel fuel [2]. The effects of biodiesel types, biodiesel fraction and physical properties on combustion and performance characteristics of a CI engine were studied. They have conducted on experiments on 4 cylinders 4 stroke DI and turbo charged diesel engine using biodiesel blends of waste oil and rapeseed oil and corn oil with normal diesel [3]. In this study performance and emission characteristics of a DI diesel engine using blends of diesel fuel with vegetable oils. They have conducted the experimental study on 4 strokes DI, Ricardo/cussons using various bio diesels such as cotton seed oil, soyabean oil, sunflower oil, rapeseed oil, palm oil, corn oil and olive kernel oil and their corresponding methyl ester at the blended ratio of 10/90 and 20/80. These biodiesel produces lower emission and improved performance [4]. The vegetable oils and their methyl esters (raw sun flower, raw cotton seed oil, raw soybean oil and their methyl esters, refined corn oil, distilled opium poppy oil and refined rapeseed) performance and emission of a four strokes, direct injection diesel engine was study [5]. They have conducted the experiments using Soybean oil, peanut oil, corn oil, sunflower oil, rapeseed oil, palm oil, palm kernel oil, and waste fried oil (vegetable oil basis). They have found that diesel engine fueled with vegetable oil methyl ester could potentially produce the same engine power as one fueled with diesel fuel, but with a reduction in the exhaust gas temperature (EGT), smoke and total hydrocarbon (THC) emissions, with a slight increase in nitrogen oxides (NO_x) emissions [6]. The bio diesel was production from Mahua (*Madhuca indica*) oil through esterification followed by transesterification. The result shows that 4% H_2SO_4, 0.33% v/v alcohol/oil ratio, 1 hr reaction time and 65°C temperature are the optimum conditions for esterification [7]. The suitability of transesterified mahua oil as a fuel in C.I. engine was evaluated. The conducted experiments

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Received February 25, 2015; **Accepted** March 25, 2015; **Published** April 01, 2015

Citation: Senthil R, Silambarasan R (2015) Performance and Emission Characteristics of Annona-Ethanol Blend Fuelled with Diesel Engine. J Fundam Renewable Energy Appl 5: 159. doi:10.4172/20904541.1000159

7B.H.P single cylinder four stroke and vertical, water cooled Kirloskar diesel engine at rated speed of 1500 rpm [8]. The mechanism of a dual process adopted for the production of biodiesel from Karanja oil containing FFA up to 20%. The conventional alkali-catalyzed route of biodiesel production does not work out effectively with high FFA feedstock such as Karanja oil [9]. Biodiesel from karanja oil (pongamia pinnata), properties and effect of biodiesel on engine the performances and emissions were measured. They conducted experiment in a single cylinder water cooled, naturally aspired, 4-strokes DI diesel engine. They have found that B100 reduced CO and smoke emissions by 50% and 45% respectively, while 15% increase in the NO_x emissions was experimented with the same fuel [10]. The experiments on single cylinder 4 strokes DI diesel engine using Annona methyl ester and its blends with diesel. They have reported that AME shows at 20% blends showed better performance and lower exhaust emissions. They have also found that CO, HC and Smoke emission was reduced and slight increase of NO_x for the the various proportions of Annona methyl ester [11]. The performance and emission characteristics of the different ethanol-jatropa and ethanol-pongamia blends were compared with that of diesel and the perfect blend is estimated by considering all the parameters pongamia-ethanol (50-50) is considered as a better fuel when compared with fuel blends [12]. The performance and emission tests were carried on Compression Ignition Engine using blends (B20, B40, B60, B80 and B100) of Jatropa Methyl Esters (JME) and diesel. Also 5% of Ethanol was injected into the intake manifold by port injection method with the assistance of a mechanical fuel injection pump. The ethanol injection assisted in getting an improved combustion process in diesel and jatropa blends [13].

Studies conducted at different injection pressures (200, 250, 300 and 350 bar) on different loading conditions showed that the higher injection pressure reduces CO and smoke emissions with respect to diesel fuel [14]. In this study E100 (100% ethanol fuel) can improve full load engine performance around whole engine speed range in a high compression ratio engine, compared to that of a base compression ratio engine operated on a premium gasoline [15].

Reduction of Particulate Matter and NO_x emissions with no serious fuel consumption penalty is achievable when the diesel-ethanol blends are used with a combination of the modern combustion control methods [16]. Ethanol is of particular interest because it is a fuel produced from all biomass including cereals, rice, and corn, and potatoes etc., crops widely produced in many places in the world [17]. A blended ethanol-based fuel is used as a substitute to conventional petroleum fuels in existing engines without modification, comprising water, a gaseous hydrocarbon (such as acetylene or propane), a binding component (such as benzene), and a lubricating oil [18].

An alcohol fuel lubricating additive mixture for use as a fuel in internal combustion engines as well as methods of preparing such mixtures [19].

The inhibitors provide a reasonable method for preventing corrosion when hydrated ethanol fuel is used [20].

This study was to increase the efficiency of rapeseed oil recovery by pressure shockwaves and to assess the changes related to energetically utilization of the seedcake obtained. Mass balances and several design parameters (along with their manifestations on the seedcake) were analyzed to allow further optimization of the technology. It was found that the use of pressure shockwaves, in combination with the mechanical expeller, may increase oil yields up to the theoretical 100% maximum, or alternatively reduce expeller energy requirements while maintaining the same oil yield. Decreased amounts of oil in the seedcake correlate with reduced amounts of volatile matter, which means lower quantities of hazardous fumes generated during direct combustion. In addition, higher levels of seedcake disintegration accelerated the biogas production [21]. Kinetic data regarding the intensity of maceration and subsequent pretreatment with pressure shockwaves (50 MPa to 60 MPa) are described in detail and evaluated statistically. Mass balances as well as the study on liquid environment are reported, allowing further process optimization according to financial aspects. It was verified on a laboratory scale by Soxhlet apparatus that oil extraction over 94% may be reached. Achieving such a high level of disintegration opens wide options for application of hydrolysis in order to break apart the remaining lignocellulose cell walls and access the last oil remaining in the vacuoles [22].

The operating principle consists of gasification of deshelled oil seeds mash using small amounts of gas. These were subsequently subjected to the pressure waves generated externally by underwater high-voltage discharges, which are then followed by expansion of the water plasma. It was observed that gasification using small amounts of gas may enhance the destruction effects of the edges of the pressure waves, resulting in deeper lignocellulose disintegration. Breakage of the cell walls increased the level of oil extraction from oil-rich vacuoles up to 93% and also accelerated the subsequent anaerobic fermentation of the presscake residue [23].

Ethanol as Fuel

General

Ethanol is ethyl alcohol (C_2H_5OH) is nowadays used as an alternative fuel for diesel. Unlike diesel, ethanol is a form of renewable energy that can be produced from agricultural feed stocks.

such as sugar cane, potato, manioc and corn.

Physical properties of ethanol

Ethanol is a volatile, colorless liquid that has a strong characteristic odor. It burns with a smokeless blue flame that is not always visible in normal light.

The physical properties of ethanol stem primarily from the presence of its hydroxyl group and the shortness of its carbon chain. Ethanol's hydroxyl group is able to participate in hydrogen bonding, rendering it more viscous and less volatile than less polar organic compounds of similar molecular weight. The properties of ethanol are compared with neat diesel fuel and Gasoline as shown in Table 1.

Combustion of ethanol

During combustion ethanol reacts with oxygen to produce carbon dioxide, water, and heat:

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O + \text{Heat}$$

After doubling the combustion reaction because two molecules of ethanol are produced for each glucose molecule, and adding all three reactions together, there are equal numbers of each type of molecule on each side of the equation, and the net reaction for the overall production and consumption of ethanol is just light into heat.

There is a reduction in calorific value by adding the ethanol along with diesel fuel is compensated by varying the supply of fuel (the fuel supply system was modified during the lower & higher load operation) during the part and full load engine operation. At full load operation, the combustion chamber temperature is high and minimum fuel will be supplied. At low load operations, the fuel supply will be maximum due to biodiesel have low calorific value and more oxygen content.

The heat of the combustion of ethanol is used to drive the piston in the engine by expanding heated gases.

Selection of biodiesel (Annona Methyl Ester) for ethanol

Annona squamosa is a member of the family of Custard apple trees called Annonaceae and a species of the genus *Annona* known mostly for its edible fruits Annona. It is commonly found in India and Cultivated in Thailand and originates from the West Indies and South America. *Annona squamosa* produces fruits that are usually called sugar apple or custard apple in English, sitafal in Marathi, sharifa in Hindi and sitaphalam in Tamil, in India and corossolier and cailleux, pommiercannelle in French. It is mainly grown in gardens for its fruits and ornamental value. It is considered as beneficial for cardiac disease, diabetes hyperthyroidism and cancer. The root is considered as a drastic purgative. The properties of AME compare with neat diesel fuel as shown in Table 2.

Ethanol blended with Annona oil

Ethanol and Annona oil are blended in various proportions and the fuel stability is studied. The fuel properties are studied and compared with diesel and shown in Table 3.

Ethanol is blended with Annona methyl ester in the proportions of 60-40, 55-45, 50-50, 45-55 and the blends are kept in observation for a week the blends are observed for any separation or precipitate formation (Figure 1).

Experimental Setup

A single cylinder, water cooled, four stroke direct injection compression ignition engine with a displacement volume of 661 cc, compression ratio of 17.5:1, developing 5.2 kW at 1500 rpm was used for the present study as shown in fig. Initially the engine was allowed to run with diesel at a constant speed of 1500 rpm for nearly 30 minutes to attain the steady state conditions at the lowest possible load. During the investigation, the temperature of lubricating oil and temperature of the engine cooling water were held constant to eliminate their influence on their results. The speed of the engine was stabilized with injected fuel to attain the temperature of lubricating oil as 65°C.Then the following observations were made twice for concordance. The exhaust gas analyzer and smoke meter was switched on quite early so that all its systems will get stabilized before the commencement of equipment and the following observations were documented (Figure 2).

Time for 50 cc of fuel consumption(s).

- Exhaust gas temperature (°C).
- Measurement of smoke using AVL smoke meter and heated Vacuum NO_x Analyser is used.
- Measurement of CO, CO_2, HC and O_2 using CRPTYON gas analyzer.
- Combustion parameters were analyzed using pressure transducer and combustion analyzer.

Properties	Diesel	Gasoline	Ethanol
Boiling point (ºC)	188 - 343	27 – 225	78
Auto ignition temperature (ºC)	210	300	420
Stoichiometric A/F ratio	14.6	14.5	9
Lower heating value (MJ/kg)	43.2	44.0	26.9
Rich Flammability Limit	7.6	6	19
Lean Flammability Limit	1.4	1	4.3
Density gm/cc	0.84	0.72	0.789

Table 1: Comparison of Ethanol properties with Diesel and Gasoline.

Properties	Diesel	AME
Cetane no	48	52
Specific gravity	0.83	0.862
Viscosity @ 40ºC	3.9	5.18
Calorific value (KJ/Kg)	43000	41000
Density (Kg/m³)	830	880.2
Flash point (ºC)	56	76
Fire point (ºC)	64	92
Oxygen Content (wt %)	-	10.8

Table 2: Fuel properties of AME and Diesel.

Testing Procedure

Experiments were carried out at steady state for different engine loads at constant speed of 1500. The engine was allowed to run for few minutes until the exhaust gas temperature, the cooling water temperature, the lubricating oil temperature, as well as the emission have attained steady-state values and data's were recorded subsequently. All the gas concentrations were continuously measured for 10 min and the average results presented. The experiment uncertainties are shown in Table 4.

The steady-state test was repeated thrice. Since the error value is too low compared with the actual values thereby error values not included in the actual result and also the equipment are often calibrated and it was kept in error free condition.

For each load condition the engine was run for five minutes and the data were collected during the last two minute of operation. The readings are tabulated and the various performance characteristics such as brake power, total fuel consumption, specific fuel consumption, brake mean effective pressure, brake thermal efficiency are calculated and various graphs are plotted.

Results and Discussion

Performance analysis of Annona - ethanol blends

Brake Specific Fuel Consumption (BSFC): The brake specific fuel consumption of various proportions of Annona Methyl Ester-Ethanol blends and diesel is shown in Figure 3. It is observed that BSFC of diesel is minimum compared with other proportions of Annona Methyl Ester-Ethanol blends at all loads. Among various proportions of Annona Methyl Ester-Ethanol blends, Annona-Ethanol (A50-E50) showed better SFC than conventional diesel fuel. BSFC is 0.297 kg/kW-hr for Annona-Ethanol (A50-E50) and 0.287 kg/kW-hr for diesel fuel at maximum load. This is due to complete combustion and also excess oxygen, high specific gravity, high viscosity and lower calorific value of biodiesel when compared to diesel. This is also due to the lower calorific value of annona methyl ester-ethanol compared with that of neat diesel fuel.

Brake thermal Efficiency (BTE): The brake thermal efficiency of various proportions of Annona Methyl Ester-Ethanol blends and diesel is shown in Figure 4. It is observed that BTE of AME and its blends are slightly lower than that of diesel fuel. The maximum BTE of diesel fuel is 30% and that of Annona-Ethanol (A50-E50) is 31.21%. Among various proportions of Annona Methyl Ester-Ethanol blends, Annona-

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	DIESEL	A-E-50-50	A-E-40-60	A-E-30-70	A-E-80-20
ETHANOL	-	50%	60%	70%	80%
ANNONA METHYL ESTER	-	50%	40%	30%	20%
INFERENCE	-	STABLE	STABLE	STABLE	STABLE
EXPERIMENTAL VISCOSITY(at 38°C) cSt	3.85	3.475	3.02	2.56	2.11
THEORETICAL CETANE NO.	45	30	25.6	21.2	16.8
THEORETICAL CALORIFIC VALUE (MJ/kg)	42.5	34.72	33.71	32.71	31.71

Table 3: Stability of Ethanol and Annona Methyl Ester.

Figure 1: Annona-Ethanol Blends

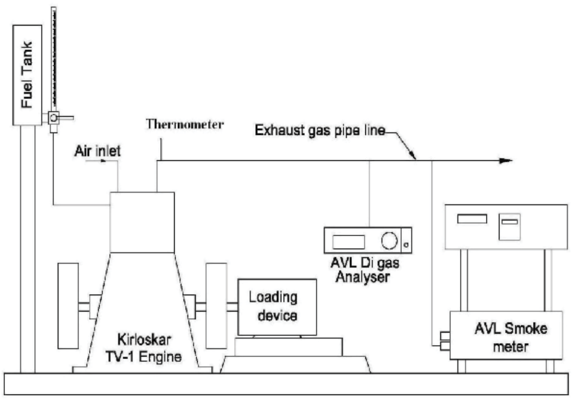

Figure 2: Experimental setup.

Parameters	Systematic Errors (±)
Speed	1 ± rpm
Load	± 0.1 N
Time	± 0.1 s
Brake power	± 0.15 kW
Temperature	± 1°
Pressure	± 1 bar
NOX	± 10 PPM
CO	± 0.03%
CO2	± 0.03%
HC	± 12 PPM
Smoke	± 1 HSU

Table 4: Experiment Uncertainties.

Ethanol (A50-E50) showed better BTE than conventional diesel fuel. This is due to The increase of BTE is due to the improvement of the combustion process on account of increased oxygen content on the annona-ethanol blends. From the fig, the faster combustion process of the annona-ethanol blend in all modes could be a contribution of the increase in BTE.

Exhaust gas temperature (EGT): The exhaust gas temperature of various proportions of Annona Methyl Ester-Ethanol blends and diesel is shown in Figure 5. It is observed that TFC is higher for all AME and its blends than diesel under various load conditions. Among various proportions of Annona Methyl Ester-Ethanol blends, Annona-Ethanol (A50-E50) showed lower EGT than conventional diesel fuel. EGT for Annona-Ethanol (A50-E50) is 189°C and 235°C for diesel at maximum load. This is due to the improved combustion provided by the annona-ethanol blends lower heating value, higher density and increased viscosity which leads to poor atomization and fuel vaporization reducing reduction of exhaust gas temperature.

Emission characteristics of Annona - ethanol

Oxides of nitrogen: The variation of oxides of Nitrogen of various proportions of Annona Methyl Ester-Ethanol blends and diesel is shown in Figure 6. The formation of NO_X in the cylinder is affected by oxygen concentration, combustion flame temperature and residence time in the high temperature zone. It is observed that NO_X emission of Annona-Ethanol (A50-E50) is minimum when compared with other biodiesels blends-ethanol and diesel at all loads. Among various proportions of Annona Methyl Ester-Ethanol blends, Annona-Ethanol (A50-E50) showed minimum NO_x emissions than other blends. It is observed that NO_X emission of 5.8% higher than conventional diesel fuel under full load condition. Obviously, with biodiesel the combustion temperature as well as the oxygen contents could be higher which leads to the higher NOx emissions. However, the higher oxygen contents of ethanol could also enhance NOx emissions. For annona-ethanol blends the cooling effect of ethanol associated with its lower calorific value and higher latent heat of evaporation could reduce the combustion temperature and hence reduce the NO_x emissions. Further annona-ethanol blends, the cooling effect of ethanol seems to be dominating effect leading to the overall reduction of NO_x emission.

Carbon monoxide emission (CO): CO is one of the intermediate compounds formed during the intermediate combustion stage of hydrocarbon fuels. CO formation depends on air fuel equivalence

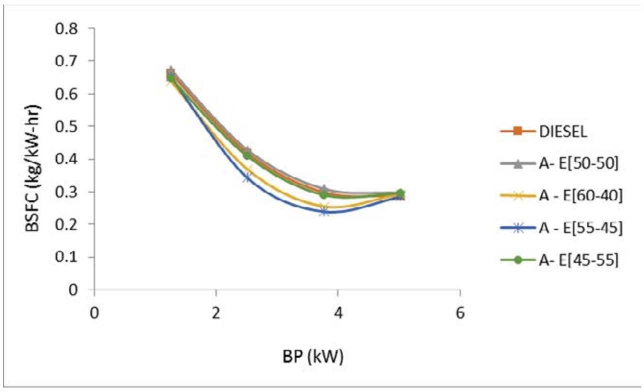

Figure 3: Brake Power (BP) vs Brake Specific Fuel Consumption (BSFC).

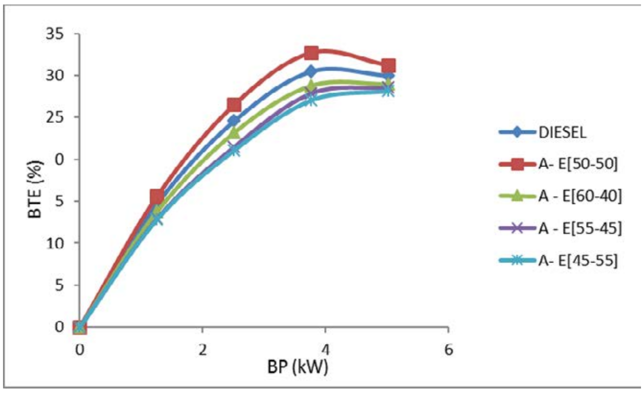

Figure 4: Brake Power (BP) vs Brake thermal Efficiency (BTE).

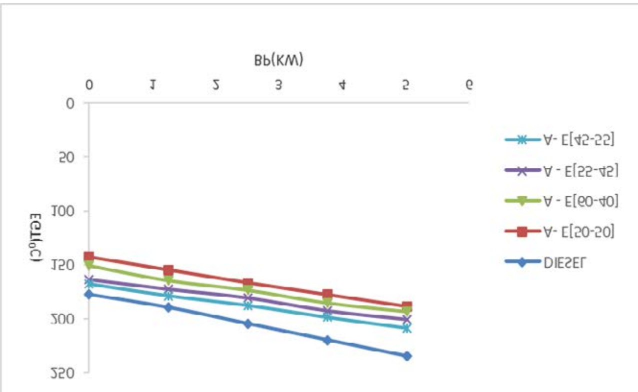

Figure 5: Brake Power (BP) vs Exhaust Gas Temperature (EGT).

ratio, fuel type, design of combustion chamber, start of injection timing, injection pressure and speed. The hydrocarbon emission of various proportions of Annona Methyl Ester-Ethanol blends and diesel is shown in Figure 7. It shows that among various proportions of Annona Methyl Ester-Ethanol blends; Annona-Ethanol (A50-E50) has lower CO emission than that of diesel at all loads. It is observed that, CO of Annona-Ethanol (A50-E50) is 0.13 % and is 0.16% for diesel at maximum load. This is due to more oxygen molecules present in the biodiesels -ethanol blends, leads to complete combustion which in turn helps in reduction of CO. For annona-ethanol blend higher oxygen content maybe the major factor leading to the reduction of CO emission. Further, the cooling effect of ethanol can increase the in cylinder gas temperature, leading to more fuel in combusted and hence reduce CO emission.

Hydro Carbon emission (HC): The hydrocarbon emission of various proportions of Annona Methyl Ester-Ethanol blends and diesel is shown in Figures 8 and 9. Among all various proportions of Annona Methyl Ester-Ethanol blends, Annona-Ethanol (A50-E50) has lower

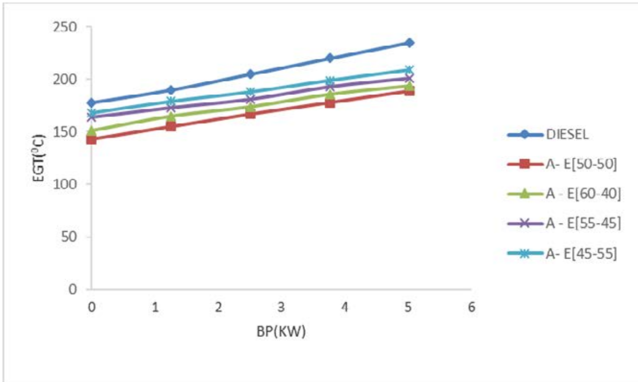

Figure 6: Brake Power (BP) vs Oxides of Nitrogen (NO_x).

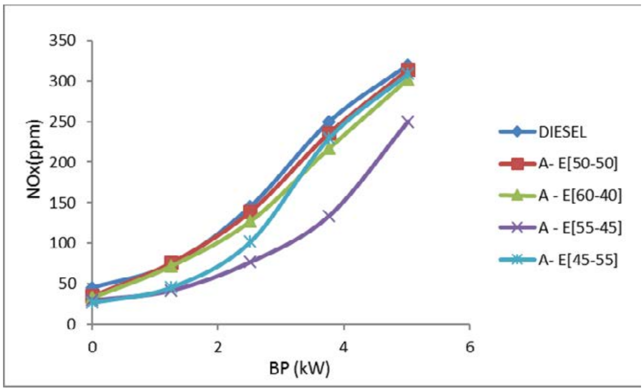

Figure 7: Brake Power (BP) vs Carbon Monoxide (CO).

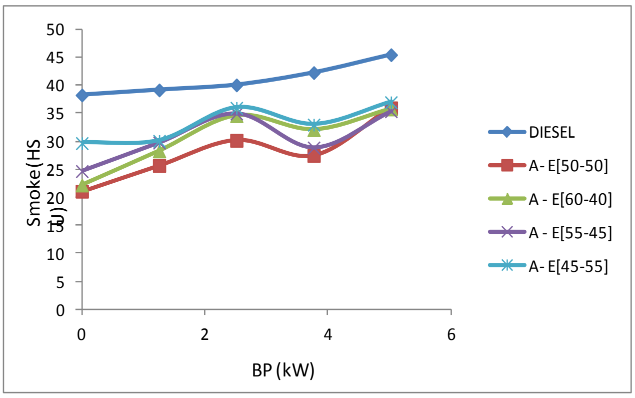

Figure 8: Brake Power (BP) vs Hydro Carbon Emission (HC).

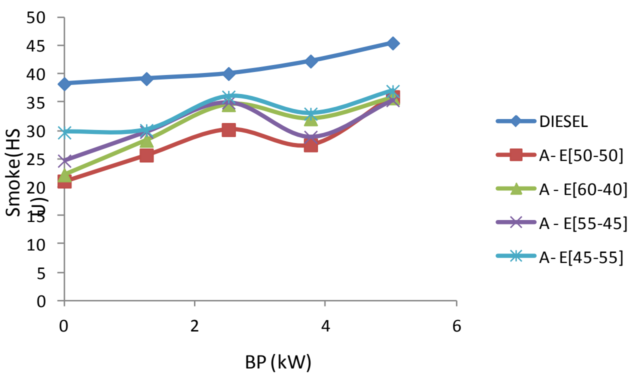

Figure 9: Brake Power (BP) vs Smoke.

HC emission than that of diesel at all loads. It is observed that HC of Annona-Ethanol (A50-E50) is 1348 ppm and 1918 ppm for diesel at maximum load. A 38% reduction of HC emission in the case Annona-Ethanol (A50-E50) as compared to diesel indicated better combustion of AME. The hydro carbon content at biodiesels-ethanol blends, which leads to better combustion when compared with diesel. HC emission for different blends of biodiesels-ethanol blends is high and Annona-Ethanol (A50-E50) shows better reduction of HC. It is due to the increase in oxygen content and reduce in viscosity and density of the blended fuel, leading to improved spray and atomization, better combustion and hence lower HC emission.

Smoke: The smoke of various proportions of Annona Methyl Ester-Ethanol blends and diesel is shown in Fig.9. It is found that smoke emission for biodiesel blends are lower than that of diesel. Among the various proportions of Annona Methyl Ester-Ethanol blends, Annona-Ethanol (A50-E50) showed much lower smoke emission. It is observed that smoke of Annona-Ethanol (A50-E50) is 36 HSU and 45.5 HSU for conventional diesel fuel. This is due to the inbuilt oxygen presence in the biodiesel- ethanol which helps in better and nearly complete combustion. It is also due to the dilution of aromatics, which are soot producers. The ethanol reduces the soot precursors due to the production of OH radicals by the ethanol. Finally it is found that the reduction of smoke could be attributed to the improved premixed combustion mode.

Conclusion

The performance and emission characteristics of the different ethanol- Annona blends are compared with that of neat diesel and the perfect blend is estimated using the results obtained. Based on the experimental results, the conclusion can be summarized as follows

1. Compared with neat diesel fuel the brake thermal efficiency slightly increases with annona-ethanol (50-50), while there is no significant difference with other proportional blends.
2. Compared with neat diesel fuel, annona-ethanol (50-50) gives slightly low HC and CO emission in all test conditions while other proportions of annona-ethanol blends have slight increase of HC and CO emission at low and high loads.
3. The annona-ethanol (50-50) have lower NO_x and smoke emissions compared with neat diesel fuel, while there is no significant difference among the biodiesel-ethanol blends at medium and high loads
4. By considering all the parameters Annona -ethanol (50-50) is considered as a better fuel compared to other fuel blends.

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