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Experimental analysis of Combustion and Emissions characteristics of CI Engine Powered with Diethyl Ether blended Diesel as Fuel

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Abstract

The emission norms becoming very stringent and the price of the fuel shooting its height, there is a need for reducing the emissions and to improve the performance of the engine. In CI engine, the combustion is heterogeneous and the time allowed for mixing of fuel with air in particular oxygen is very less so there is partial mixing of the fuel which makes the mixture rich at certain places leading to the formation of particulate matter and very leaner at some places leading to formation of NO_x*. Some research outcomes shows that oxygenate when mixed in the fuel prior to combustion can improve the performance and also reduces the emissions. In this research the DEE is mixed with Diesel for 5% and 10%, and the combustion and emission characteristics are analysed. The result shows promising characteristics in performance improvement and Emission reduction.*

Keywords: Combustion, emissions, engine powered

Introduction

The rapid urbanization, increased vehicular population and the decreasing availability of the fossil fuels have created awareness for effective utilization of the available fuel. Although CI engines have a higher thermal efficiency when compared with SI engine, advanced research in the combustion of diesel fuel in CI engine shows that the Brake thermal efficiency, Brake power can further be increased by allowing the fuel to combine with more oxygen atoms to form complete combustion, this also reduces the smoke, CO and HC emissions. The oxygen composition in the combustion chamber can be increased by adding oxygenates in the diesel fuel. Oxygenates like ethanol, 1-propanol, 1-butanol, 1-pentanol, 2-methoxyethanol, 2-ethoxyethanol, 2-butoxyethanol dibutyl ether and methanol are widely used[1]. Ethanol is used in SI engines to improve the combustion, it has a higher octane value, but for CI engine ethanol has poor cetane value, so it is not possible to use in CI engines. When Ethanol is dehydrated diethyl ether is obtained which has a cetane number of 125 which is very good as a fuel[2]. DEE has some promising properties. Diethyl ether has the potential to supplement the fuel with oxygen to improve combustion and emission characteristics of diesel engines[3]. DEE is a renewable energy source and it is used as an cold start aid in early period but its usage as a fuel blend is fairly minimum[4]. Diethyl ether was tested for their Particulate emissions and the results shows that PM reduction levels were influenced largely by the oxygen content of the blend, high radical concentrations produced by the oxygenates in the premixed flame zone promote the oxidation of carbon to CO and CO_2, limiting carbon availability for soot precursor formation. With a blending ratio of 95:5 diesel to DEE performance and emission test were reported in[4], At higher loads, B5 blend results in higher brake thermal efficiency as compared to other blends. But it results in higher NO_x emission. This may be due to the higher combustion temperature; also there is a drastic reduction in smoke emission with the addition of DEE. Higher blends such as B5, B6 and B7 resulted in lower smoke emission. But B5 results in lower CO and HC emission compared to other blends at higher loads. The ignition delay period is analysed and it is found that the short ignition delay of DME revealed in engine tests is due to the short physical delay of DME. The evaporation rate of DME droplets is about twice that of diesel-fuel droplets at the same cylinder condition. In plain diesel engine, stoichiometric condition cannot be attained anywhere before temperatures of droplets in the spray reach 225°C in comparison, the stoichiometric condition in a DME spray is attained immediately. To reduce the ignition delay period some research have been conducted by varying the ambient temperature and combustion chamber oxygen concentration, results shows that the NTC (negative temperature coefficient) regime with respect to the ignition of homogeneous mixture is found at the low ambient gas oxygen concentration conditions. The oxygenated fuels used in their experiment have higher ignition quality than that of gas oil at all ambient gas conditions at the temperature range from 700K to 1000K; the net pressure rise histories have a two-stage behaviour. The two-stage ignition behaviours become clear with decreasing ambient gas oxygen concentration[5]. Research on the influence of oxygenated diesel fuels on the PM/NOx emission trade-off was carried out with use of 11 different synthetic oxygenated compounds, representing 3 chemical groups (glycol ethers, maleates, carbonates). Each of oxygenates were evaluated as a fuel additive at a concentration of 5% v/v in the same base diesel fuel. The changes in PM/NOx emissions caused by oxygenates not only depended on oxygen content in fuel but also on the oxygenate type and its properties. Among the three chemical groups of oxygenates which representatives were tested, glycol ethers produced the least favourable changes in PM/NOx trade-off. Maleates produced higher than glycol ethers reduction in PM emissions and moreover actually with no increase in NO emissions. Carbonates, like glycol ethers, caused an increase in NOx emissions, but they reduced PM emissions the most effectively[6]. Though various analyses were done in improving the performance and reducing the emissions little emphasis was given to the study of combustion characteristics analysis. In this research a complete analysis of the effect of DEE blending in diesel is done and the results are in match with standard testing conditions.

Material and Methods

The specification of the engine is shown in the table 1, conventional diesel is used as the base fuel and test fuel blends were prepared with 5% and 10% DEE in diesel. Engine used in this investigation is a stationary diesel engine, which is usually used for agricultural and low power generation purposes. A swinging field electrical dynamometer was used to apply the load on the engine. This electrical dynamometer consists of a 5-kVA AC alternator (220V, 1500rpm) mounted on bearings and on a rigid frame for the swinging field type loading. The output power was directly obtained by accurately measuring the reaction torque by a strain gauge type load cell. A water rheostat with an adjustable depth of immersion electrode was provided to dissipate the power generated.

The pressure inside the combustion chamber was measured using an AVL GH12D miniature pressure transducer connected to an AVL3066A02 Piezo Charge Amplifier. The pressure transducer was mounted on the cylinder head at the centre to minimize any error. The crank angle and the position of top dead centre (TDC) were measured using an AVL364 Angle Encoder, mounted rigidly on the camshaft of the engine. The outputs of the charge amplifier and the encoder were connected to an AVL 615 Indimeter A/D card, which converts analog input to digital output. A thermocouple in the exhaust pipe measured the exhaust gas temperature, which is considered as an indication of temperature obtained in the combustion chamber as a result of combustion of fuel.

Data acquisition system: AVL 615 Indimeter software was used to analyse the output data of the A/D card. This generates a pressure-crank angle diagram that indicates the pressure variation at every crank angle, heat release rate at every crank angle and a result table. The result table indicates at which crank angle (a) the combustion starts and (b) the percentage (10%, 50% & 90%) of heat released during the combustion. Variation of all these parameters can be observed, through a personal computer as the engine runs. To record all these values at a particular load, measurement of all these parameters were carried for 100 cycles and an average value of these cycles can be recorded as a measured parameter at that load. Hence the combustion parameters such as cylinder pressure, heat release rate, ignition delay, peak pressure and crank angles was obtained.

Testing was conducted at various loads starting from no load up to the rated load. The engine was operated for 15 minutes at each load, to stabilize the engine under new conditions. The tests were conducted at the rated engine speed. The engine was first fuelled with diesel oil, and the under steady state conditions, combustion parameters were recorded at various loads. The engine was then fuelled with DEE blend and the tests were performed.

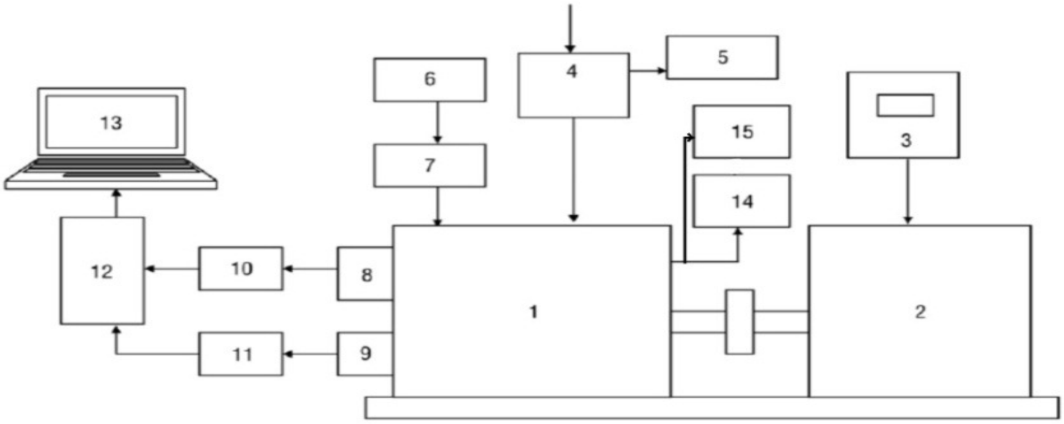

Figure-1
Schematic diagram of the experimental setup
i. Engine, ii. Swinging field Electrical dynamometer, iii. Dynamometer controls, iv. Anti-pulsating tank, v. Manometer, vi. Diesel tank, vii. fuel measurement flask, viii. pressure pickup, ix. crank angle encoder, x. charge amplifier, xi. TDC amplifier circuit, xii. A/D card, xiii. Personal computer, xiv. exhaust gas analyser, xv. smoke meter

Table-1
Specification of the Engine

Manufacturer	Kirloskar Oil Engine Limited, India.
Engine Model	TAF 1
Engine Type	Vertical, single cylinder, 4 stroke, direct injection, Air cooled, Compression ignition Engine.
Rated power	4.4 KW at 1500 rpm
Injection pressure	210 bar
Loading type	Eddy current dynamometer
Compression Ratio	17.5 : 1
Bore/stroke	110/87.5(mm)
Start of injection	23^0 BTDC

Table-2
Properties of the Fuel

Property	Diesel	DEE	5% DEE	10% DEE
Chemical Structure	C12H26	C_2H_5-O- C_2H_5	-	-
Density (kg/m^3)	830	713	807	806
Viscosity(C.P.) mm^2/sec (20 C^0)	2.7	0.23	-	-
Auto ignition point(C^0)	200-420	160		
Lower Heating Value (MJ/kg)	42800	33.9	43.01	42994
Cetane Number	50	>125	-	-
Rich Flammability limit (%vol) Lean	-	9.5 to 36 1.9	-	-
Oxygen content (%Wt)	1-3	21	6.71	6.96
Boiling point (C^o)	180-330	35	-	-
Stoichiometric A/F Ratio	14.6	11.1	14.87	14.81
Latent Heat of Vaporization (kJ/kg)	-	356	-	-

Gas analyser and Smoke meter specifications: AVL Digas 444 gas analyser was used to measure the constituents of CO, CO_2, HC, NOx and O_2 in the exhaust gas which is interfaced with RS 232 C, pick up, oil temperature probe. AVL 437 Smoke meter of IP 52 type is used to measure the exhaust gas opacity, absorptivity and smoke temperature.

Fuel Properties: DEE with the specification as shown in the table 2 is obtained and it is blended with conventionally used Diesel for various proportions and the basic tests were performed for the different blends.

Results and Discussions

Experiments were carried out with 5% DEE and 10 % DEE blend. When the DEE composition was further increased beyond 10% the engine became unstable and heavier smoke were observed. This may be due to the phase separation of the blend, which results in cavitation in the injector nozzle and it leads to poor injection of fuel in to the combustion chamber. Cavitation also results in reduction in injection pressure. This pressure reduction results in large droplets and non-uniformity of atomization. These large droplets of fuel starve of oxygen necessary for burning. This results in highly smoky exhaust and poor efficiency at higher blends.

Total Fuel Consumption: With the increase in load the amount of fuel required to produce the necessary brake power increases and with the increase in the addition of the DEE the total fuel consumption reduces more in the low load conditions and it is almost the same at peak load conditions. DEE being an oxygenate increases the combustion efficiency and makes an effective utilization of the fuel, converting CO and HC into CO_2 and H_2O (figure 2).

Brake Specific Fuel Consumption: The BSFC is higher for lower loads and it decreases in the mid loads and remains the same for peak loads. The BSFC is lower for 10 % DEE blend. This is due to better combustion of diesel fuel, which results in higher heat release. The cylinder pressure of 10% DEE was higher than other blends and diesel. This increase in cylinder pressure results in higher power output. Hence, there is a considerable saving in the fuel. When the DEE composition is further increased, due to decrease in the calorific value of the fuel the BSFC increases (figure 3).

Brake Thermal Efficiency: The increase in brake power with reduced fuel consumption at higher loads helps to increase the BTE at higher loads. With the reduction in the fuel consumption and the effective burning of HC in the fuel the heat energy is obtained at its maximum from the fuel. The presence of oxygen in the DEE blend helps in complete combustion of the fuel raising the BTE. The brake thermal efficiency is almost equal for all the fuels at lower loads due to increase in ignition delay. At the higher load condition, the brake thermal efficiency slightly increases due to the longer ignition delay leads to a rapid increase in premixed heat release rate that affects brake thermal efficiency favourably[7]. The increase in BTE may be due to the ability of DEE to reduce the surface tension or inter facial tension between two or more interacting immiscible liquids helped the better atomization of fuel, which improves the combustion of diesel (figure 4).

Nitrogen Oxides: As the load increases the deficiency for Oxygen increases to burn the fuel and NO_x emissions decreases. The reduction in the peak combustion temperature due to the addition of the DEE which in turn reduces the calorific value of the fuel blend helps in reducing the NOx emissions. The higher cetane number and reduced ignition delay period helps in reducing the NO_x emission. It shows that NOx emission slightly decreased with DEE because the combustion duration of the blend is shortened. This reduced ignition delay lowers the mass of the fuel accumulated before combustion and lowers the initial combustion rates, hence decreasing the peak temperature thus reducing the NO_x formation[8]. Some researchers reported that there is an increase in the NO_x emissions with the addition of the DEE as it helps in complete combustion of the fuel resulting in increase of combustion chamber temperature[9,10,11] (figure 5).

Hydrocarbon: With the addition of DEE the hydrocarbon emission increases, this may be due to the fact that DEE has a higher cetane number(>125) but when blended with diesel its cetane number decreases raising the ignition delay period, higher the ignition delay period more the Hydrocarbon emissions. The reduction in peak cylinder pressure may also contribute to the increase in Hydrocarbon emission (figure 6).

Carbon Monoxide: CO emissions is higher at both lower and higher brake power but it is at its minimum at intermediate power. This is typical with all internal combustion engines since at low loads the air fuel ratio is too low and air fuel ratio decreases with increase in load. With blending of DEE the CO emissions increases slightly this is due to the incomplete combustion of the fuel due to over leaning of the mixture this happens both at lower and higher engine loads (figure 7).

Smoke Opacity: The smoke opacity remains the same at both high and low power situations and it decreases at intermediate power modes. The increase in smoke opacity is due to the incomplete combustion of the fuel hydrocarbon. The increase of DEE composition in diesel increases the Smoke opacity; this may be due to the phase separation of the blend (figure 8).

Exhaust Gas Temperature: The exhaust gas temperature almost remains the same for the Increase in the volume of DEE in diesel. The exhaust gas temperature for 5% DEE is higher compared with 10%DEE this may be due to the difference in calorific value of the fuel, 5% DEE supports combustion in a better way than 10% DEE as it over leans the mixture. The diethyl ether has a high latent heat of evaporation value than diesel; hence it gives lower exhaust gas temperature (figure 9).

Pressure Curve: With the addition of DEE the peak pressure reduces this is due to lower calorific value of the DEE blended fuel and reduced ignition delay period and retarded injection[12]. With the addition of further DEE a similar kind of reduced peak pressure were obtained. This may be due to reduction in the premixed combustion and the lower heat release of the DEE blends; as peak pressure mainly depends upon the combustion rate in the initial stages, which is influenced by the fuel taking part in uncontrolled heat release phase. A similar kind of results were reported[13]. It states that peak pressure reduces at high outputs with introduction of diethyl ether due to reduction in ignition delay and retarded injection. There is a sharp decrease in the peak cylinder pressure for 10% blended DEE than 5% blend of DEE (figure 10).

Heat Release Rate: It is clear from the heat release versus crank angle plot that there is a sharp decline in the heat release rate with the addition of DEE. The heat release starting time is also offset by the ignition delay period. More the DEE addition with base fuel more the decrease in HRR. DEE has a high cetane number and high latent heat of vaporization which tends to decrease the ignition delay. The cylinder temperature is decreased as more DEE is evaporated[14] (figure 11).

Ignition Delay Period: As the percentage of DEE in the fuel blend is increased there is decrease in the ignition delay period, this is more pronounced at higher engine loads compared with light loads. The factor which attribute to this may be the higher cetane number of DEE and higher latent heat of vaporization. At the low load, less DEE is injected and in this condition, the high cetane number may become a dominant factor, leading to a short ignition delay and small premixed fuel during the ignition delay. In contrast to this case, at the high load, more DEE is injected. The higher latent heat of vaporization may become the dominant factor. DEE evaporation will have a great influence on the decrease in cylinder temperature and increases the ignition delay, the premixed mixture will increase during the ignition delay and it will lead to an increase in peak pressure of DEE blend (figure 12).

Mass Burned Period: The period for burning the fuel is increased with the addition of DEE to 10% and the fuel is burned quickly with 5% addition of DEE compared with base fuel. The change in mass burn period is sharp between 5% to 10% of DEE addition. At 5% DEE the higher cetane number and reduced ignition delay period may help to burn the fuel quickly but at 10% the reduction in the calorific value of the fuel may tend to increase the mass burned period (figure 13).

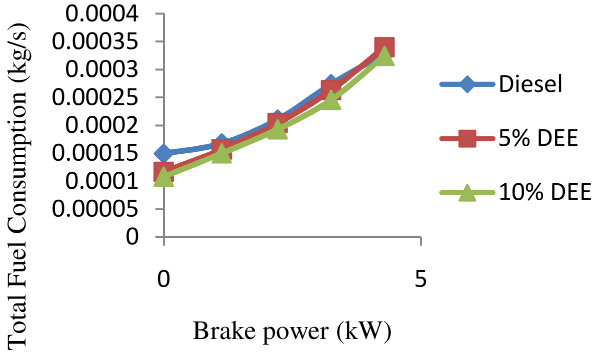

Figure-2
Total Fuel Consumption

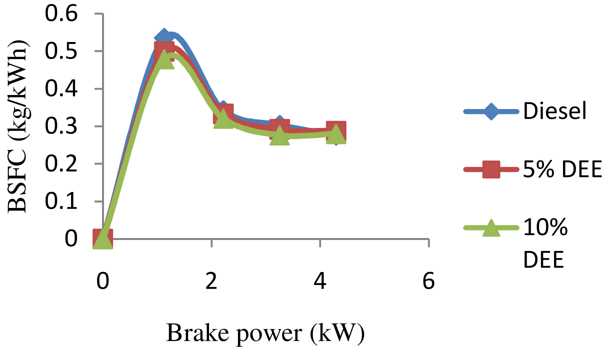

Figure-3

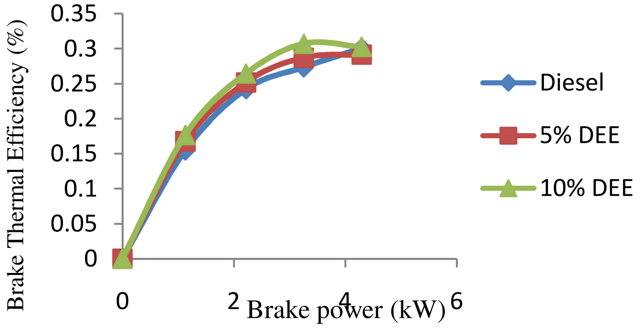

Figure-4
Brake Specific Fuel Consumption

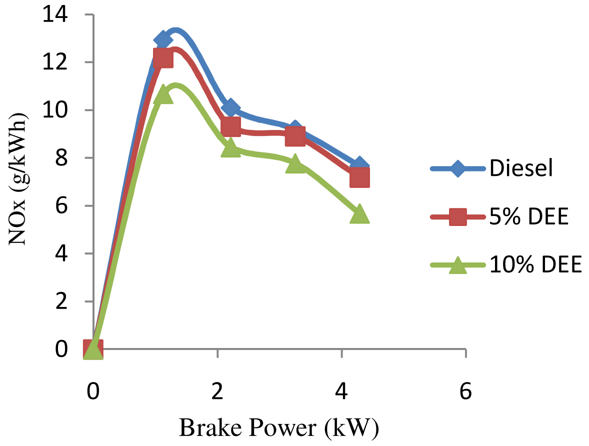

Figure-5
Brake Thermal Efficiency

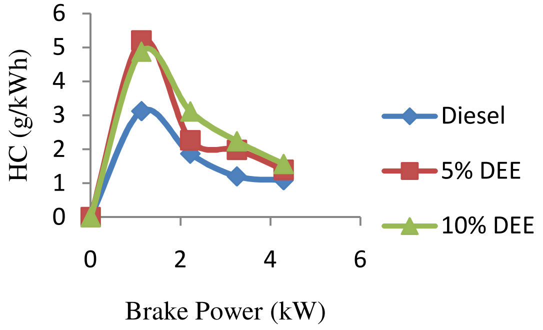

Figure-6
Hydrocarbon

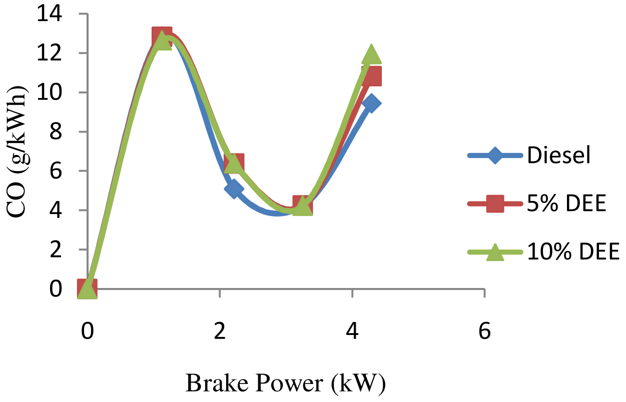

Figure-7
Carbon Monoxide

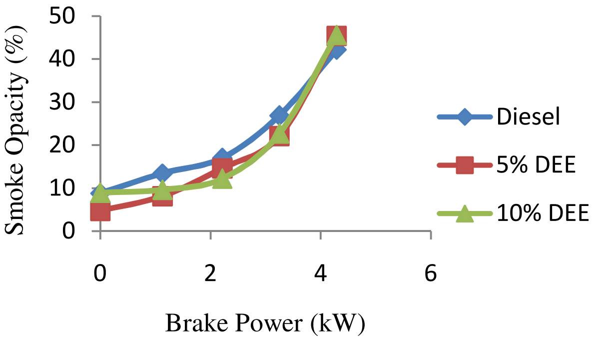

Figure-8
Smoke Opacity

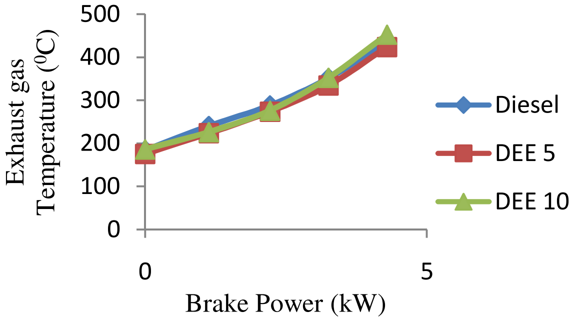

Figure-9
Exhaust Gas Temperature

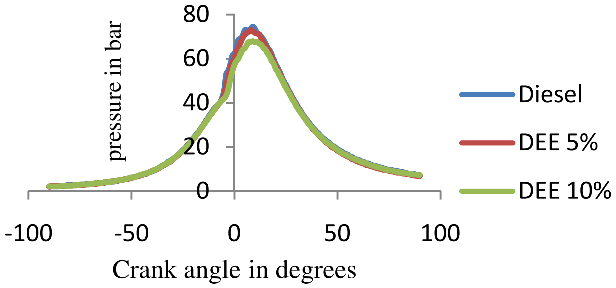

Figure-10
Pressure Curve

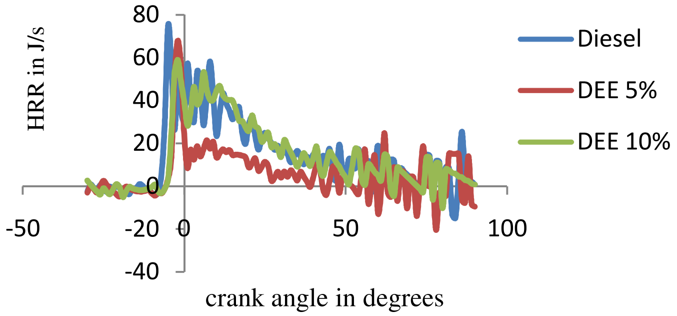

Figure-11
Heat Release Rate

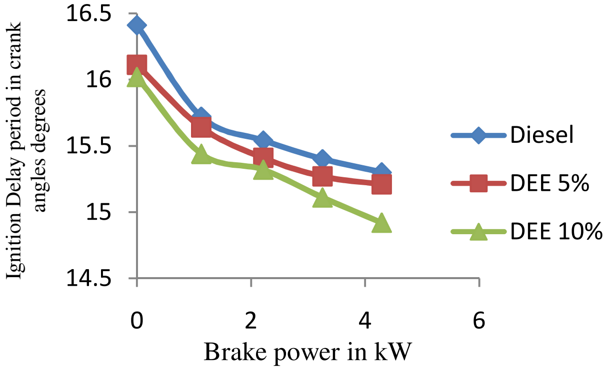

Figure-12
Ignition Delay Period

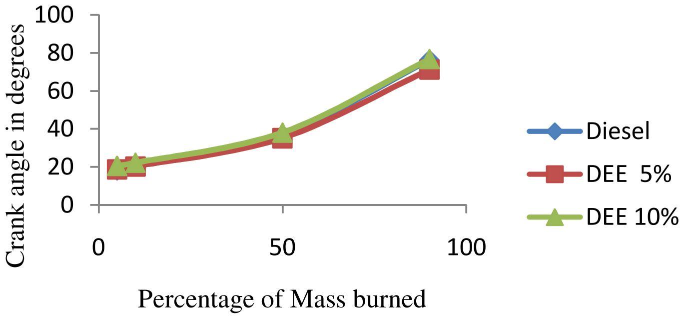

Figure-13
Mass Burned Period

Conclusion

Blending DEE with diesel and its usage in conventional diesel engine increases the brake thermal efficiency and reduces the BSFC. The NO_x emissions are reduced and there is a an increase in the CO and HC emission this can be avoided if optimum DEE and Diesel fuel blending ratio is used without making the fuel mixture to be too lean. The high latent heat of evaporation of DEE counter acts the cetane benefit which increases the HC emission.

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