Advances in Automobile Engineering
ISSN: 2167-7670

Banapurmath et al., Adv Automob Eng 2015, 4:1
DOI: 10.4172/2167-7670.1000117

Research Article Open Access

Alcohol (Ethanol and Diethyl Ethyl Ether)-Diesel Blended Fuels for Diesel Engine Applications-A Feasible Solution

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Abstract

The objective of improving the combustion, reducing the pollutants and to enhance the performance of diesel engines have intensified research in diesel engines. The goal of this study was to percept the combustion, performance and emission characteristics of diesel engine using oxygenated fuels (blending agents). In view of this, experimental investigations were carried out on a single cylinder four stroke direct injection water cooled diesel engine using ethanol and diethyl ether blended fuels in different volume ratios with diesel fuel. The experimental investigation was performed with four different blends of ethanol (E0 -neat diesel, E5, E10, E15 and E20)and diethyl ether (DEE0 - neat diesel, DEE5,DEE10, DEE15 and DEE20) to assess the impact of using ethanol and diethyl ether-diesel blends on diesel engine performance, combustion and emissions. In addition, 2% Ethyl acetate has been added to ethanol diesel blend to retain homogeneity and prevent the interfacial tension between two liquids. For the same rated speed and compression ratio, different blended fuels as well as pure diesel, various engine parameters such as brake thermal efficiency and fuel consumption, combustion parameters such as peak cylinder pressure and exhaust emissions such as smoke opacity, hydrocarbon, CO, and NOx, were measured. The results indicate that the brake thermal efficiency increased with an increase in ethanol and DEE contents in the blended fuels at overall operating conditions. At higher loads, reduced CO emission levels were observed for blends of ethanol and DEE at high load. HC emissions increased for all blends of ethanol and DEE compared with diesel fuel due to high fuel consumption and high latent heat of vaporization which lowers cylinder temperatures and causes the emission of unburned hydrocarbons at lower load. NOx emission slightly reduced with ethanol and DEE blends compared to diesel at lower loads. Further, due to lower calorific value and high latent heat of vaporization of ethanol and DEE results in reduced flame temperature and lower NOx emissions. The NOx emission is almost identical compared to diesel at higher engine loads. Ethanol and DEE showed lowest smoke emissions at high engine loads compared to diesel fuel operation.

Keywords: Engine power; Oxygenates; Synthetic fuel; Ethanol diethyl ether; Optimization; Stabilization; Blending; Homogeneity

Introduction

Diesel engines are the most popular well known efficient prime mover among the internal combustion engines because of their simple, robust construction coupled with high thermal efficiency and specific power output with better fuel economy, much longer life span and reliability which results in their wide spread use in transportation, thermal power generation and many more industrial and agricultural applications. Inspite of many advantages, the diesel engine is inherently dirty and is the most significant contributor of various air polluting exhaust gases such as particulate matter (PM), oxides of nitrogen (NOx), carbon monoxide (CO) and other harmful compounds which contribute to serious public health problems. Particulate matter (PM) emissions from diesel combustion contribute to urban and regional hazes. Nitrogen oxides (NOx) and hydrocarbons (HC) are precursors for O_3 and PM. NOx emissions from diesel vehicles play a major role in ground-level ozone formation. Ozone is a lung and respiratory irritant causes a range of health problems related to breathing, including chest pain, coughing, and shortness of breath. Particulate matter has been linked to premature death, and increased respiratory symptoms and disease. In addition, ozone, NO, and particulate matter adversely affect the environment in various ways, including crop damage, acid rain, and visibility impairment.

In view of increased concerns regarding the effects of diesel engine particulate and NOx emissions on human health and the environment and more stringent government regulation on exhaust emissions, reducing the NOx and particulate emission from diesel engines is one of the most significant challenges. A lot of research work has taken up in this direction to develop after treatment and in-cylinder control techniques by modifying fuels to mitigate the tailpipe NOx emission and formation in the cylinder respectively. It is difficult by using the traditional way to simultaneously reduce NOx and PM in diesel engine owing to the existing of trade-off curve between NOx and PM. The rapid depletion, uneven distribution of petroleum fuels, their ever increasing costs and great concern over pollution led to search for an alternative fuel to replace conventional fuels. The most promising alternative possibility to clear this critical issue is to use the oxygenated fuels either in pure form or blended with diesel to provide sufficient oxygen and promote combustion and reducing PM emission and possibly decreasing NOx emission. Oxygenated fuels are the attractive class of synthetic fuels in which Oxygen atoms are chemically bound within the fuel structure. This Oxygen bond in the oxygenated fuel is energetic and

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Received May 14, 2015; **Accepted** June 01, 2015; **Published** June 05, 2015

Citation: Banapurmath NR, Khandal SV, RanganathaSwamy L, Chandrashekar TK (2015) Alcohol (Ethanol and Diethyl Ethyl Ether)-Diesel Blended Fuels for Diesel Engine Applications-A Feasible Solution. Adv Automob Eng 4: 117. doi:10.4172/2167-7670.1000117

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provides a chemical energy that result in no loss of efficiency during combustion. The optimization of oxygenated fuels, to be used either as, neat fuel or as an additive, offers significant potential for reduction in particulate emission. In this study, two oxygenates are tested with diesel in blended form to investigate the performance, combustion and emissions of a diesel engine. Ethanol is one of the renewable, bio based and eco-friendly oxygenates for internal combustion engine. It can be produced from any biomass feedstock containing carbohydrates such as corn, wheat, sugar-beets, potatoes, maize and sugarcane etc. In addition, ethanol has higher heat of vaporization, oxygen content and flammability temperature and therefore has a positive influence on engine performance and emission characteristics of CI engine.

Diethyl ether, also known as ethoxyethane, ethyl ether, sulfuric ether, or simply ether, is an organic compound in the ether class with the formula $(C2H5)_2O$. It is a colorless, highly volatile, flammable liquid produced as a byproduct of the vapor-phase hydration of ethylene to make ethanol. Diethyl ether has a high cetane number of 85-96 and is used as a starting fluid, in combination with petroleum distillates for gasoline and diesel engines, due to its high volatility and low flash point.

Several researchers have conducted experimental investigation on the diesel engine fuelled with diesel blended fuels. Some of them are briefly highlighted in the following section.

Xiangang [1] and Banapurmath [2] observed lower particulate matter (PM) emission with the increase of oxygenate content in the blends, and ethanol addition into diesel fuel increases HC, CO, NOx and NO emissions and decreases particle number concentration. Increased brake thermal efficiency has been reported with diesel/biodiesel-ethanol blends operation. Gnanamoorthi [3] showed that increased peak in-cylinder pressure and higher heat release occurs closer to TDC for ethanol blend and it increases with increase in ethanol in the blend. There was CO and HC emissions and found that which is closer than those with base fuel up to 30% ethanol, but much higher CO and HC emission with 40% and 50% ethanol and there is a slight decrease in NOx emission. Ahmet Murcak [4] reported high engine power for DE10 at an engine speed of 3000 rpm and 45°CA advanced injection angle. Further, the maximum engine torque has been reported for DE10 at1400 rpm and injection advance of 25°CA. The minimum brake specific fuel consumption (BSFC) was obtained forDE20 blends in 1200 rpm and injection advance of 35°CA. Baskar [5] conducted experiments on diesel engine under different load conditions using various fuel combinations. They showed both Diphenyl ether and Diethelene glycol dimethyl ether blends substantially lowers the exhaust gas opacity. The maximum reduction 60% has been reported with Diphenyl ether 15 and Diethelene glycol dimethyl ether 15 blends as compared to base reference diesel fuel. In addition, oxygenated diesel blends have shown significant reduction in CO and HC emissions with only a slight penalty of NOx emissions. Oxygen enrichment of the conventional fuel is not accompanied by a sharp increase of the in-cylinder NO concentration due to decrease of the local temperature as a result of the lower fuel heating value. Oxygenated diesel fuels produce a favorable shift in PM/NOx trade-off. Javier [6] conducted the engine performance tests on direct injection compression ignition engine fueled with butanol/diesel fuel and pentanol/diesel fuel blends (in a range from 10% to 30% butanol and 10% to 25% pentanol) and reported that the existence of oxygen in the molecular structure of 1-butanol and 1-pentanol offsets its reduced LHV, showing better combustion resulting in increased BTE, while power and torque were found to be similar to diesel fuel. Butanol blends exhibit slightly better BSFC behavior than pentanol blends and neat diesel fuel. Nurun [7] have reported that the combustion with oxygenated fuels were much faster than that of conventional diesel fuel. This was mainly due to the oxygen content in the fuel molecular structure and the low volatility of the oxygenated fuels. The lower volatile oxygenated fuel evaporated earlier and very good air-fuel mixing was achieved during combustion which eventually resulted in lower exhaust emissions. Miyamoto [8] investigated the combustion and emissions of diesel engine operated on different types of oxygenates in a single cylinder, four stroke cycle, DI diesel engine. They reported significant improvements in smoke, particulate matter, NO_x, HC, engine noise and thermal efficiency with the oxygenated fuels. Manuel and Gonzalez [9] focused study on selecting most promising oxygenate compounds as blending components in diesel fuel for an advanced engine testing with an objective of reducing particulate emissions in the exhaust. The results have shown that PM emission reductions were proportional to the oxygen content of the fuel. Both Tripropylene Glycol Mono-Methyl Ether and Di Butyl Maleate oxygenated test fuels contained 7% wt. oxygen and their total PM emissions were found to be similar. David and Hilden [10] evaluated performance of reference base diesel and five blends containing oxygenates. The experimental results have shown that oxygenated fuels reduced PM and NO_x under some operating conditions, but produced little effect on either HC or CO emissions. Aliphatic oxygenates at 6 wt. percent oxygen in the reference fuel reduced PM emissions by 15-27%. Dhandapani [11] have shown that the combustion characteristics with ethanol addition improved in-cylinder peak pressure, cumulative heat release (CHR), rate of heat release (ROHR), in-cylinder peak temperature and combustion duration. Regarding emission characteristics the experimental results showed significant reduction in smoke, carbon monoxide (CO) and total hydrocarbon (THC) emissions with extended oxygen mass percentage in the fuel at higher engine loads. However, increased oxides of nitrogen (NOx) emissions has been reported at high loads although the common tradeoff between smoke and NOx was found to be more prominent for the oxygenated fuels. Gvidonas [12] observed lower NOx levels with ethanol blended fuels and HC emissions for richer combustible mixtures whereas the influence of a higher ethanol mass content on CO emissions and smoke opacity depends on the air-fuel ratio and engine speed. Octavio Armas [13] showed that slight increase in NOx and THC emissions, while reduced CO emissions were found with these alcohol blended fuels. Particle mass (PM) was estimated from both the smoke opacity and particle size distributions. In both cases, important benefits were observed with alcohol blends. Dulari Hansdah [14] carried out experimental investigations in a single cylinder, four stroke, air cooled direct injection (DI) diesel engine, fueled with bioethanol, adopting the fumigation technique. The results indicated that, the bioethanol fumigation showed an overall longer ignition delay of 2-3°CA for all the flow rates in comparison with diesel, at full load. The maximum brake specific nitric oxide (BSNO) and smoke emissions were found to be lower, by about 24.2% and 25% in the bioethanol fumigation, compared to that of diesel operation at full load. Subramanian [15] carried out experimental investigations to assess the effect of using diethyl ether to improve performance and emissions of a DI diesel engine running on water-diesel emulsion. It was found that use of neat water diesel emulsion significantly lowered NO_X and smoke levels as compared to neat diesel operation. It also increases the brake thermal efficiency at high outputs. However, there is a rise in HC, CO emissions and ignition delay. Nagdeote [16] carried out experimental investigation to evaluate the effects of using diethyl ether and ethanol as additives to biodiesel/diesel blends on the performance and emissions of a direct injection diesel engine. The test fuels were denoted as DI (100% diesel), BD (20%biodiesel and 80% diesel in vol.), BDET (15% biodiesel, 80% diesel, and 5% diethyl ether in vol.) and BDE (15% biodiesel ,80% diesel and 5% ethanol, in vol.) respectively. The results shows that, compared with BD, slightly lower brake specific fuel consumption (BSFC) for BDET was observed. Drastic reduction in smoke is observed with BDET and BDE at higher engine loads. BDET reflects better engine performance and combustion characteristics than BDE and BD. Sulakshana [17] carried out the experimentation to study the effects of blends DB10, DBE10, DBE20 i.e. diesel 90% -10% biodiesel, diesel 80% -10% biodiesel - 10% ethanol, diesel 70% - 10% biodiesel - 20% ethanol for same diesel engine. The results showed maximum BP for blended fuels of DB10, DBE10, DBE20 dropped by 3.65%, 6.17% and 7.58% respectively compared with neat diesel fuel. Maximum BSFC for blend DB10, DBE10, DBE20 increased by 7.69%, 7.82%, and 33.62% respectively compared with neat diesel fuel. Blend DBE10 has optimum viscosity and calorific value which gives slightly less brake torque and brake power. Diesel-ethanol-biodiesel blends showed reduced NOx, PM, Smoke with slight increment in HC emissions while keeping CO emissions at same level compared with diesel fuel. Finally by considering all parameters DBE10 was best alternative fuel. SayiLikhitha [18] investigated the effect of blending of Diethyl ether (DEE) with diesel at various proportions (5%, 7.5% and 10%) on the performance of diesel engine. The experimental results indicated that with the increase in the concentration of DEE to diesel increases the brake thermal efficiency, mechanical efficiency and decreases the specific fuel consumption.

Experimental Setup

Experiments were conducted on a Kirloskar TV1 type, four stroke, single cylinder, water-cooled diesel engine test rig fuelled diesel. Figure 1 shows the line diagram of the test rig used. Eddy current dynamometer was used for loading the engine. The fuel flow rate was measured on the volumetric basis using a burette and stopwatch. The engine was operated at a rated constant speed of 1500 rev/min. The emission characteristics were measured by using HARTRIDGE smoke meter and five gas analyzer during the steady state operation. Experimentation is carried out with the hemispherical shaped combustion chamber provided in the existing engine at an injection pressure of 205 bar with an injector of 3 holes of ϕ 0.3 mm at an injection timing of 23° bTDC. Finally the results obtained were analyzed. Properties of the fuels used viz. HS diesel, ethanol and diethyl ether are shown in Table 1. The specification of the compression ignition (CI) engine is given in Table 2.

Results and Discussions

This section explains the performance, emission and combustion characteristics of the diesel and oxygenated blended fuels like ethanol and diethyl ether in different proportions.

Performance characteristics

Brake thermal efficiency: Figure 2 shows the variation of BTE at different loads for different blends of ethanol. BTE increases with an increase in load for all blends. As the percentage of ethanol in the mixture is increased, improvement in the brake thermal efficiency can be observed compare to neat diesel fuel. This is due to better combustion because of the presence of oxygen, which involves higher combustion efficiency. With ethanol- diesel fuel blend operation, the high latent heat of evaporation of ethanol which produce more cooling effect that results in low exhaust gas temperature which tends to lesser the heat loss through exhaust and hence higher brake thermal efficiency can be obtained. In addition, ethanol has a lower flame temperature than neat diesel fuels thereby limiting the heat losses in the cylinder, which further enhance the BTE. Figure 3 shows the variation in Brake thermal efficiency (BTE) at different load for different DEE blends. The BTE increases at higher loads for all the blends. The addition of DEE increased the BTE. This is due to the presence of oxygen in the DEE helps in the complete combustion of the fuel. The BTE is almost same at the lower loads for all blends of DEE and base diesel and then increases slightly with increase in concentration of DEE to diesel. As the percentage of DEE in the mixture is increased, improvement in the brake thermal efficiency can be observed compare to neat diesel fuel. This is due to ability of DEE to reduce the interfacial tension between two or more interacting immiscible liquids helped the better atomization of fuel, which improves the combustion of diesel.

Emission characteristics

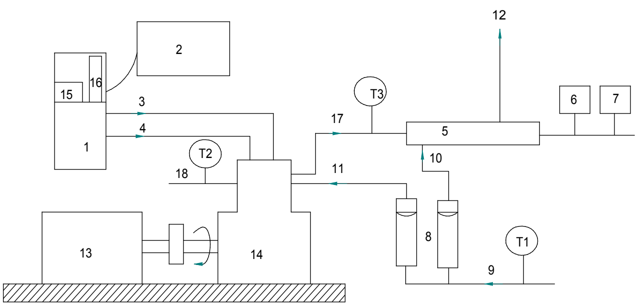
Smoke emissions: Figure 4 illustrates the smoke emissions with engine loads for different ethanol blend percentage. Smoke is direct

Sl No	Property	Diesel	Ethanol	Diethyl ether
1	Molecular Weight	181 g/mol	46 g/mol	74.1216 g/mol
2	Molecular Formula	$C_{13}H_{24}$	C_2H_6O	$C_4H_{10}O$
3	Appearance	Light yellow liquid	Colorless liquid	Colorless liquid
4	Density	850 kg/m^3	789 kg/m^3	713.4 kg/m^3
5	Boiling point	266°C	78°C	34.6°C
6	Flash point	85°C	14°C	−45°C (228 K)
7	Volatility	Volatile	Volatile	Highly volatile
8	Kinematic viscosity at 40°C	3.05 cSt	0.795 cSt	0.223 cSt
9	Auto-ignition temperature	316°C	422°C	160°C
10	Heating value	43000 kJ/kg	29700 kJ/kg	33892 kJ/kg
11	Surface tension at 20°C	0.023 N/m	0.022 N/m	0.017 N/m
12	Latent heat of vaporization	250 kJ/kg	922 kJ/kg	376 kJ/kg
13	Flammability	Flammable	Flammable	Flammable
14	Cetane number	45-55	8	85-89
15	Boiling point	188-344°C	78°C	34°C
16	Carbon content (% weight)	84-87	52.2	64.86
17	Hydrogen content (% weight)	33-16	13.1	13.5
18	Oxygen content (% weight)	0	34.7	21
19	Stoichiometric air-fuel ratio	15	9	11.1

Table 1: Properties of the fuels used.

Sl No	Parameters	Specification
1	Type of engine	Kirloskar make Single cylinder four stroke direct injection diesel engine
2	Nozzle opening pressure	200 to 205 bar
3	Rated power	5.2 KW (7 HP) @1500 RPM
4	Cylinder diameter (Bore)	87.5 mm
5	Stroke length	110 mm
6	Compression ratio	17.5 : 1

Table 2: Specifications of the engine.



1-Control Panel, 2-Computer system, 3-Diesel flow line, 4-Air flow line, 5-Calorimeter, 6-Exhaust gas analyzer, 7-Smoke meter, 8-Rota meter, 9, 11- Inlet water temperature, 10-Calorimeter inlet water temperature,12-Calorimeter outlet water temperature, 13-Dynamometer, 14-CI Engine, 15-Speed measurement,16-Burette for fuel measurement, 17-Exhaust gas outlet, 18-Outlet water temperature, T1-Inlet water temperature, T2-Outlet water temperature, T3-Exhaust gas temperature.

Figure 1: Experimental set up.

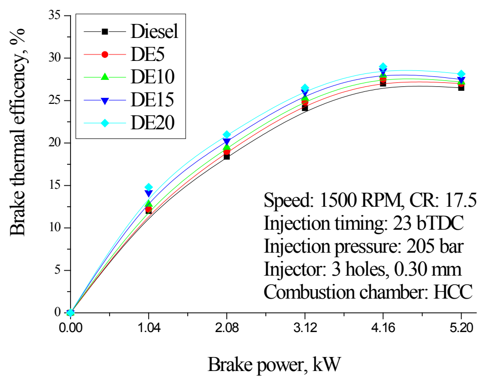


Figure 2: Variation of BTE with load for differentetanol blends percentage.

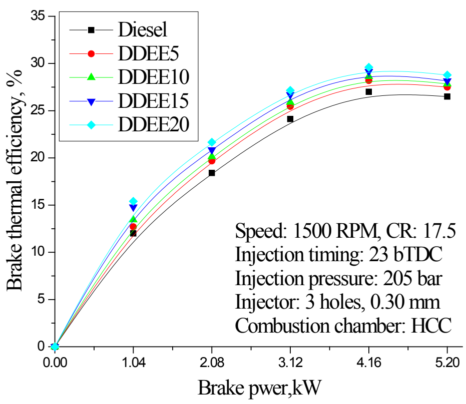


Figure 3: Variation of BTE with load for different DEE blends percentage.

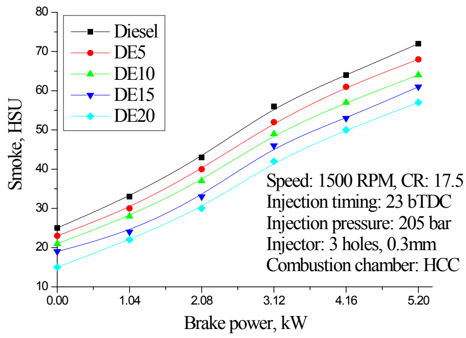


Figure 4: Variation of Smoke emission with load for different ethanol blend percentage.

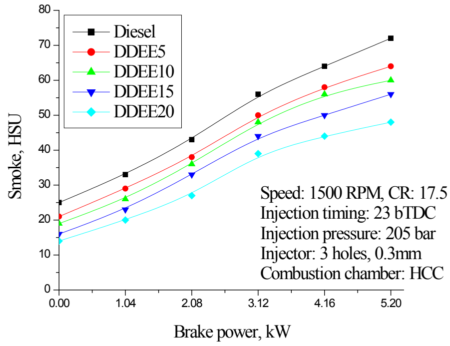


Figure 5: Variation of Smoke emission with load for different DEE blend percentage.

indication of incomplete combustion in the engine and is formed in fuel rich regions in the combustion chamber. Smoke emission is higher at low loads, which may be due to short combustion cycle at high speed, long delay period and shortage of oxygen which may be due to improper mixing or usage of rich fuel. Smoke emission is higher with ethanol blends at lower loads than diesel. This is because of poor evaporation rate of blended fuel due to high latent heat of evaporation of ethanol. At high loads, the flame temperature is high, which results in low smoke emission with ethanol blends than the base fuel. Figure 5 shows the variation of smoke emissions with engine loads for different DEE blend percentage. The smoke emissions are reduced with DEE blend. This may be due to overall leaning operation of the engine as the combustion is assisted by the presence of the fuel-bound oxygen of the diethyl ether. Additionally, high volatility of diethyl ether has a remarkable effect on the reduction of smoke emissions, especially at high engine loads; hence DEE shows the lowest smoke emissions at high engine loads.

HC emissions: HC is partially burned and unburned fuel emission. Figure 6 shows the variation of HC with load for different percentage of ethanol blends. At lower loads, HC emissions increased for all blends compared with diesel fuel due to low cetane number of blends, high fuel consumption and high latent heat of vaporization which lowers cylinder temperatures which causes the emission of unburned hydrocarbons. At higher load, no noticeable change in HC emissions for the blends and remains almost same as that of diesel fuel.

Figure 7 shows the variation of HC with load for different percentage of DEE blends. At lower loads, HC emissions increased for all blends compared with diesel fuel due to high fuel consumption and

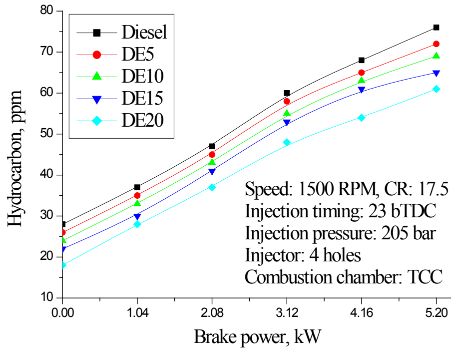


Figure 6: Variation of HC emission with load for different ethanol blend percentage.

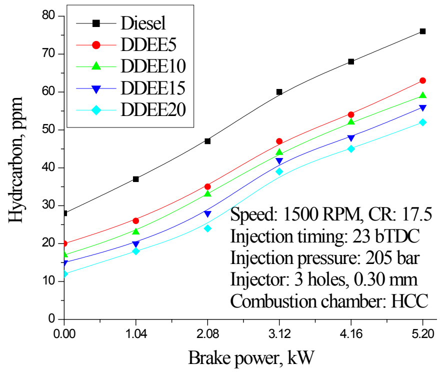


Figure 7: Variation of HC emission with load for different DEE blend percentage.

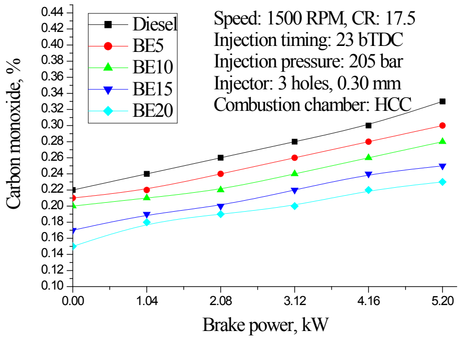


Figure 8: Variation of CO emission with load for different ethanol blend percentage.

high latent heat of vaporization which lowers cylinder temperatures which causes the emission of unburned hydrocarbons. At higher load, no noticeable change in HC emissions for the blends and remains almost same as that of diesel fuel.

CO emissions: Figure 8 shows the variation of CO with load for different percentage of ethanol blends. It is formed as a result of incomplete combustion. CO emissions are higher at lower loads. This due to fact that in ethanol, the oxygen atom is connected to carbon atom with a very strong bond and it is difficult to break that bond because of decrease in the cylinder gas temperature at low load condition. In addition, ethanol has a lower cetane number and high latent heat of evaporation than the diesel. At low load, there is not enough vaporization and hence very less time to burn fuel completely that results in considerable increase in CO emissions. At higher loads, the speed decreases and hence enough time available for combustion to occur, better mixing and inbuilt fuel oxygen that results in complete combustion and hence slightly reduced the CO emissions, for blends at high load. At full load, there is no significant change between the fuels for CO emissions. Figure 9 shows the variation of CO with load for different percentage of DEE blends. CO emissions are higher at lower loads. This due to fact that at low load condition, although DEE has higher cetane number, its latent heat of evaporation is slightly higher than that of diesel; as result there is not enough vaporization and hence very less time to burn fuel completely that results in considerable increase in CO emissions. At higher loads, enough time available for combustion to occur, better mixing and inbuilt fuel oxygen that results in complete combustion and hence slightly reduced the CO emissions, for blends at high load. At full load, there is no significant change between the fuels for CO emissions.

NOx emissions: Figure 10 shows the variations of NOx emissions with engine loads for different ethanol blend percentage. The rate of formation of NOx is primarily a function of flame temperature, the residence time of nitrogen at that temperature, and the availability of oxygen in the combustion chamber. It can be observed from the Figure that the NOx emission is increased with the engine load. This is due to increased quantity of fuel is injected and combusted in the cylinder when engine load increases, which causes higher gas temperature and results in more NOx formation in the engine cylinder. It also can be seen that the NOx emission is slightly reduced with ethanol blend

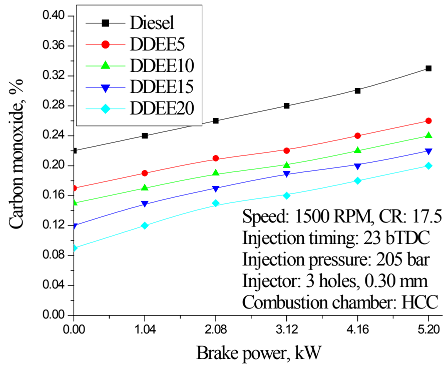


Figure 9: Variation of CO emission with load for different DEE blend percentage.

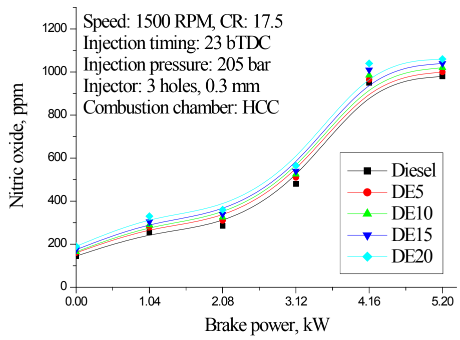


Figure 10: Variation of NOx emission with load for different ethanol blend percentage.

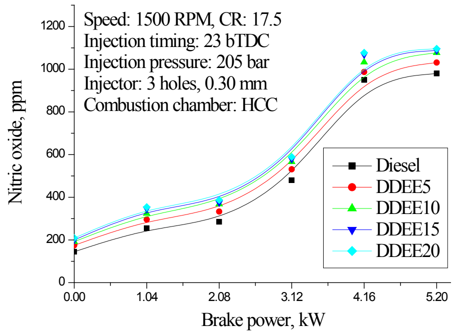


Figure 11: Variation of NOx emission with load for different DEE blend percentage.

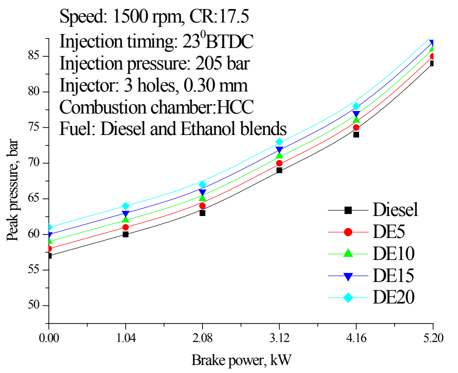


Figure 12: Variation of peak pressure with brake power for different ethanol blend percentage.

compared to diesel at lower loads. This is because of ethanol usage, the combustion temperature is low due to low calorific value and the high latent heat of vaporization of ethanol results in reduced flame temperature and lower NOx emissions, which provides less heat energy after combustion. With the increased engine load, more fuel is injected then higher combustion temperature; the availability of oxygen in the reaction regions has an increased effect on the NOx formation. The NOx emission is almost identical compared to diesel at higher engine loads. Figure 11 shows the variations of NOx emissions with engine loads for different DEE blend percentage. It is observed from the Figure that NOx emission is slightly reduced with DEE blend compared to diesel at lower loads. This is due to low combustion temperature because of low calorific value and the high latent heat of vaporization of DEE results in reduced flame temperature and lower NOx emissions. At higher loads, due to increased quantity of fuel injection, the combustion temperature and oxygen availability is more; as a result NOx emission is almost identical compared to diesel.

Combustion characteristics

Peak pressure: Figure 12 shows the variation of peak pressure with brake power for diesel ethanol blends which is higher than that of the neat diesel. Auto ignition temperature of the fuel is a predominant element which causes variations in the shape of the curve in the pressure angle diagram of engine. Due to combustion of diesel with lower self -ignition temperature, peak pressure is obtained initially, and then a depression is formed due to continuous heat absorption by ethanol due to its high latent heat for vaporization. When auto ignition condition of ethanol is reached in the cylinder, combustion takes place and hence sudden rise of temperature and pressure is observed. With the increase of ethanol, ignition retards and combustion duration shortens, which contributes to rapid ethanol combustion.

Figure 13 shows the variation of peak pressure with brake power for diesel DEE blends, which is similar to that of the neat diesel. Auto ignition temperature of the fuel is a predominant element which causes variations in the shape of the curve in the pressure angle diagram of engine. Since the auto ignition temperature of DEE is lesser than that of the diesel, latent heat of evaporation and cetane number is higher than that of the diesel and due to stabilization of the mixture, combustion takes place and hence sudden rise of temperature and pressure is observed.

Combustion duration: Figure 14 shows the variation of combustion duration with brake power for different ethanol blend percentage with diesel. Combustion duration increased with load and decreased with ethanol blend percentage. The trend could be due to the lower auto ignition temperature of ethanol compared to diesel, higher latent heat of evaporation and cetane number than that of the diesel. Figure 15 shows the variation of combustion duration with brake power for different DEE blend percentage with diesel. Combustion duration increased with load and decreased with DEE blend percentage. The trend could be due to the lower auto ignition temperature of DEE compared to diesel, higher latent heat of evaporation and cetane number than that of the diesel. Combustion duration observed with DEE was slightly lower than ethanol for all percentage blends.

Ignition delay: Figure 16 shows the variation of ignition delay with

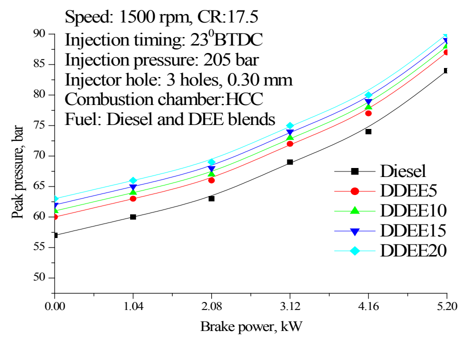


Figure 13: Variation of peak pressure with brake power for different DEE blend percentage.

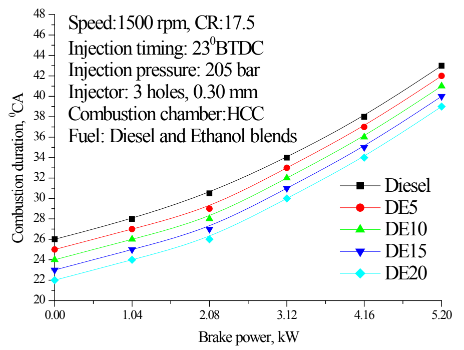


Figure 14: Variation of combustion duration with brake power for different ethanol blend percentage.

Citation: Banapurmath NR, Khandal SV, RanganathaSwamy L, Chandrashekar TK (2015) Alcohol (Ethanol and Diethyl Ethyl Ether)-Diesel Blended Fuels for Diesel Engine Applications-A Feasible Solution. Adv Automob Eng 4: 117. doi:10.4172/2167-7670.1000117

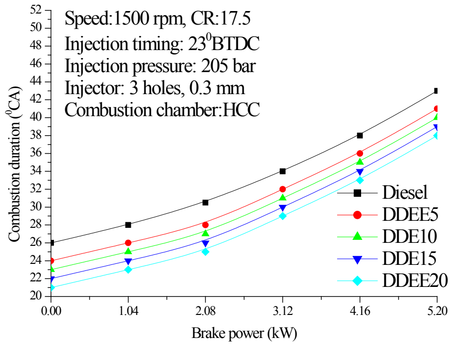


Figure 15: Variation of combustion duration with brake power for different DEE blend percentage.

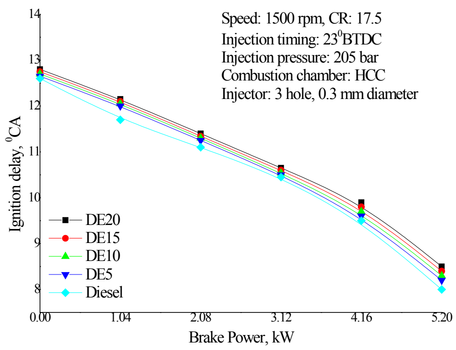


Figure 16: Variation of ignition delay with brake power for different ethanol blend percentage.

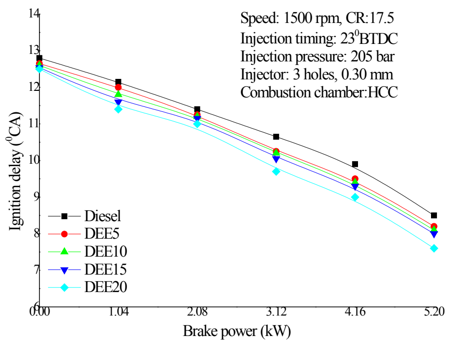


Figure 17: Variation of ignition delay with brake power for different DEE blend percentage.

brake power for different ethanol blend percentage with diesel. Ignition delay decreased with load and increased with ethanol blend percentage. The trend could be due to the lower auto ignition temperature of ethanol compared to diesel, higher latent heat of evaporation and cetane number than that of the diesel. Figure 17 shows the variation of ignition delay with brake power for different DEE blend percentage with diesel. Ignition delay decreased with load and increased with DEE blend percentage. The trend could be due to the lower auto ignition temperature of DEE compared to diesel, higher latent heat of evaporation and cetane number than that of the diesel.

Heat release rate (HRR): Figures 18 and 19 shows the variation of heat release rate with crank angle for diesel and different diesel ethanol and diesel-DEE blends at 100% loading conditions which occurs closer to TDC. The peak heat release rate increases with an increase in both ethanol and DEE concentration in the diesel. The ethanol and DEE as an oxygenator improves combustion for all fuel blends and faster laminar flame speed of ethanol and DEE that results in sudden heat release rate than that of diesel. The heat release curve has slightly negative depression during the ignition delay period. This is due to loss of heat from the cylinder during fuel vaporization phase. During the premixed combustion, higher heat is released with ethanol and DEE blend than diesel due to higher ignition delay, which may be due to higher latent heat of evaporation and lower cetane number of ethanol and DEE in the blend. Diesel being common the type of alcohol added is responsible for the observed trends as shown in Figure 19.

Conclusions

The existing single cylinder CI engine was suitably modified to operate on diesel and alcohol (Ethanol and DEE) blend sat near diesel operating conditions. From the experimental study, the effect of blend ratio on the performance of diesel engine operated with diesel and two alcohols the following conclusions were drawn for different loading conditions.

- For diesel and alcohol fuelled blends in diesel engine the BTE showed increasing trend with increased blend ratio of alcohol in diesel up to 20% in general and with DEE-diesel in particular. However blends beyond 20% were not considered due to separation of the diesel and alcohol fuels. Compared to

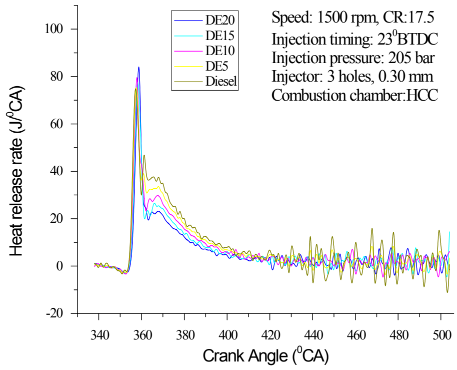


Figure 18: Variation of heat release rate with crank angle for different ethanol blend percentage.

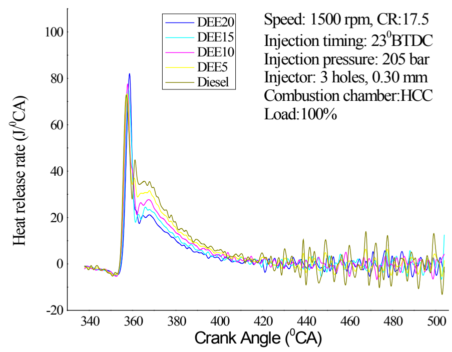


Figure 19: Variation of heat release rate with brake power for different DEE blend percentage.

neat diesel both alcohol-diesel blended fuels showed improved performance in terms of increased BTE.

- HC, CO and smoke emissions reduced with increased alcohol concentration in diesel fuel while they increased with increased loading conditions. DEE-diesel blends showed lower emissions compared to ethanol-diesel blends. However NOx emissions increased with increased alcohol content in diesel fuel.
- Ignition delay, combustion duration, decreased with increased alcohol content in the diesel fuel, while peak pressure and heat release rates increased.

On the whole it can be concluded that the modified single cylinder engine operated with alcoholic-diesel blended fuels worked satisfactorily with improved engine performance compared to neat diesel fuel operation. This experimental work showed the capability of both alcoholic fuels which are renewable energy sources to replace diesel partially and is the need of hour. Finally from the experimental study it can be said that DEE can be a good option for reducing fossil fuel usage in diesel engines and pave the way for the energy security of the country due to escalating fossil fuel prices with dependency on such fuels.

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