International Journal of Emerging Technology and Advanced Engineering
Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 153-159
An ISO 9001:2008 certified Int. Journal, ISSN 2250-2459, available online at www.ijetae.com

PERFORMANCE AND COMBUSTION CHARACTERISTICS OF DI-DIESEL ENGINE USING NEAT MME WITH DEE

P. Ramesh Babu [1+], Dr. V. Rambabu [1], S. Ravi Babu [2]

[1]*Associate Professors,*
Department of Mechanical Engineering
GMRIT-Rajam, Srikakulam Dist,
Andhra Pradesh-India

[2]*Assistant Professor,*
Department of Mechanical Engineering
GMRIT- Rajam, Srikakulam Dist.
Andhra Pradesh-India

[+]Corresponding author email:rameshbabu.p@gmrit.org,rbpothula@gmail.com

ABSTRACT

Bio-diesels and their blends are proven alternative fuels for petroleum diesel. But still the research work is going, on the bio-diesels application to make it environmental friendly. Particulate matter and oxides of nitrogen are the main pollutants in the tail pipe emissions of bio-diesel fueled engine. In this paper, mahuva methyl ester along with diethyl ether (DEE) used as fuel for the single cylinder DI-Diesel engine, analysis of combustion pressure and heat release rate with respective to the crank angle and performance and emission analysis is presented. In this experiment DEE mixed with the mahuva methyl ester (MME) at different proportion such as 3%, 5% 10% and tested at different loads on diesel engine. Smoke levels are decreased substantially with 15% DEE blend with MME at full load. The thermal efficiency rise and SFC are better in the case of 15% additive blend..

Keywords: Oxygenated fuels, dimethyl ether, mahuva methyl ester, diethyl ether, combustion pressure.

1. INTRODUCTION

Fuel companies and the researchers around the world are devoted to reduce such emissions with different ways. Particulate matter (PM) and oxides of nitrogen (NOx emissions) are the two important harmful emissions in diesel engine. Fuel modification, modification of combustion chamber design and exhaust after treatment is the important means to alleviate such emissions. In this context, engine researchers are hunting suitable alternative fuels for diesel engine. Among different alternative fuels, oxygenated fuel is a kind of alternative fuel. The presence of oxygen in the fuel molecular structure plays an important role to reduce PM and other harmful emissions from diesel engine.

Additions of methyl tertiary butyl ether (MTBE) and ethanol have been successful in reducing CO and non-evaporative hydrocarbon emissions from gasoline engines. The success of oxygenated gasoline has sparked interest in the use of oxygenated compounds as particulate matter (PM) emissions reducing additives in diesel fuel. Bennethum and Winsor **[1]** examined the oxygenated compound diglyme (Diethylene glycol dimethyl ether) in a 2-stroke engine. Further work in which dimethyl carbonate was added to diesel at 3.5 wt % oxygen. PM and CO reductions were approximately 15%. NOx emissions showed a 1.8% increase while HC emissions were unchanged. The neat methyl esters of rapeseed oil and soybean oil were also tested. HC, CO, and PM were decreased approximately 75%, 50%, and 30%, respectively, for both methyl esters. NOx emissions have increased by approximately 18%. Graboski et.al **[2]** has measured emissions from100% methyl esters of soy bean oil and blends of this material with no. 2 diesel in a 4-stroke engine. Substantial particulate emissions reductions were observed at all oxygenate levels. They observed a statistically significant 1% increase in NOx at 2 wt % oxygen in the fuel and higher NOx increases at higher oxygen levels.

Liotta and Montalvo **[3]** investigated the emissions effects of three glycol ethers, an aromatic alcohol, an aliphatic alcohol, and a polyether polyol using a 4-stroke engine. The actual structures of these compounds were not revealed. Methyl soy ester and diglyme were also included for comparison to previous

Presented at International Conference on Energy Resources and Technologies for Sustainable Development, 07-09 February 2013, Howrah, India.

results. Based on heavy-duty transient testing, CO was generally reduced and NOx showed an increase with all oxygenates studied. The PM reduction experienced appeared to be related to the amount of oxygen in the fuel. Unregulated emissions of aldehydes and ketones were reported to decrease. Nikanjam **[4]** examined ethylene glycol monobutyl ether acetate as a diesel additive based on cost, fuel blending properties, and toxicity concerns. Emissions results from a 4-stroke engine showed CO and PM reductions of approximately 18% and a NOx increase of 3% for 3 wt % oxygen in the fuel.

Ullman et al. **[5]** reported the effect of oxygenates and other fuel properties on emissions from a 1994 Model Detroit Diesel Series 60, 4-stroke engine. Monoglyme and diglyme were used as oxygenates at the 2% and 4% oxygen levels. The engine was run with 5 and 4 g/bhp.h NOx calibrations (1994 and 1998 emissions standards, respectively). Statistical models of the emissions dependency on fuel composition were developed with weight percent oxygen as the oxygenate variable. At 2% Oxygen and constant aromatic content and Cetane number, the model predicts a 1.5% increase in NOx for the 5-gram calibration and a 0.9% increase for the 4-gram calibration. FEV Engine Technology **[6]** investigated various soy ester blends with diesel in comparison to diesel using a 13-mode steady-state test with the Navistar 7.3 L engine. FEV found that NOx increased with biodiesel under all conditions of speed and load. Soy ester blends reduced particulate at high speed and at all loads. At lower speeds, particulate was reduced at light and heavy loads but was increased at intermediate loads.

DEE is oxygenated fuel that has a very high Cetane number. Masoud et al. **[7]** reported lower smoke and THC emissions due to higher Cetane number and Oxygen content of DEE. Authors also found lower CO emissions at high load condition, but higher at low load condition. Also lower NOx emissions were realized with DEE-diesel blends. Kapilan et al. **[8]** conducted experiments with 5 % DEE and found lower CO, THC and smoke emissions while a slight improvement in thermal efficiency was observed. Yeh et al. **[9]** investigated the effect of fourteen different oxygenated fuels on diesel emissions, especially PM and NOx emissions. Authors found that for PM reduction, the most effective oxygenates on equal oxygen content basis were the C9 – C12 alcohols in both the engine and vehicle testing.

The present work reports on the effect of oxygenated fuel on diesel combustion and exhaust emissions. It has been found that the exhaust emissions including PM, total unburnt hydrocarbon (THC), carbon monoxide (CO), smoke and engine noise were reduced with oxygenated fuels. NOx emissions were reduced in some cases were increased depending on the engine operating conditions. The reductions of the emissions were entirely depended on the oxygen content of the fuel. It has been 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 eventually resulted in lower exhaust emissions.

2. PREPARATION & CHARACTIZATION OF MME

The use of vegetable oils in lieu of diesel fuel in conventional diesel engines requires certain modification of their properties. The problems of substituting diesel fuels with pure vegetable oils (non-edible) are mostly associated with their high viscosities. Transesterification is the general term used to describe the important class of organic reactions, where an ester is transformed into another ester through interchange of alkyl groups and is also called as alcoholysis. Transesterification is an equilibrium reaction and the transformation occurs by mixing the reactants. However, the presence of a catalyst accelerates considerably the adjustment of the equilibrium. The general equation for trans-esterification reaction is given below in Fig.1.

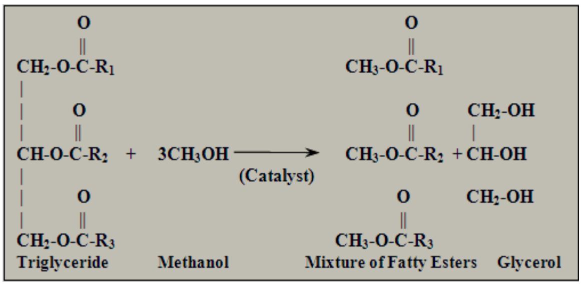

Fig.1. Mechanism of the base-Catalyzed Transesterification Process.

The basic constituent of vegetable oils is triglyceride. Vegetable oils comprise of 90-98 percent triglycerides and small amounts of mono-glyceride, diglyceride and free fatty acids. In the transesterification of vegetable oils, a triglyceride reacts with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acid alkyl esters and glycerol. The overall process is a sequence of three consecutive and reversible reactions in which diglyceride and mono-glycerides are formed as intermediates. The stoichiometric reaction requires one mole of triglyceride and three moles of alcohol. However, an excess of alcohol is used to increase the yield of alkyl esters and to allow phase separation from the glycerol formed.

The mechanism of the base-catalyzed trans-esterification reaction of vegetable oil is shown in the Fig.2.

ISSN 2250-2459, *Volume 3, Special Issue: ICERTSD 2013, Feb 2013, pages 153-159*

Fig.2 Base treatment

The first step according to the general equation is the reaction of the base with the alcohol, producing an alkoxide and the protonated catalyst. The nucleophilic attack of the alkoxide at the carbonyl group of the triglyceride generates a tetrahedral intermediate, from which an alkyl ester and the diglyceride are formed. The latter deprotonates the catalyst, regenerates the active species, and enables it to react with a second molecule of the alcohol thus starting another catalytic cycle. Diglycerides and mono-glycerides are converted by the same mechanism to a mixture of alkyl esters and glycerol.

Table 1: Characteristics of DEE & Comparison with MME

Property	Diesel	*MME*	*DEE* (additive)
Viscosity (cSt)@RT	2.75	4.25	0.23
Density (kg/m^3)	0.830	0.899	0.713
Cetane number	45	50	>125
Calorific Value (kJ/kg)	43000	36,700	33,900
Boiling point	180-360 ^0C	*360^{0}C*	*35^{0}C*
Auto ignition temperature	250^{0}C	>300^{0}C	160^{0}C

Because of lower density difference (Table.1), blending is not difficult as there is no separation observed. The additive is having higher Cetane value and lower density, lower auto ignition temperature and boiling point indicates that it starts ignition and initiates ignition of the main fuel i.e. biodiesel. The quantity of additive is limited to 15% of the main fuel is understood from the tail pipe emissions.3% mixture of additive is going in consonance with the 15% additive similar in all aspects but there is a zone of equivalence ratio in which 15% additive plays important role in saving fuel and running the engine smooth as per the vibration signatures investigated. The additive prepares for better combustion of the main fuel because of its better combustion characteristics in advance and elevates the stature of combustion to higher strata to enhance the efficiency to better levels when compared to petro diesel. The start of combustion will be initiated by the additive to finish it to smoother end. Better combustion with lesser detonation can be observed from the vibration signatures in comparison at 15% of additive mixing. Reducing delay period by increasing mixture temperature by earlier combustion of DEE is the advantage associated with the doping. Earlier combustion of DEE leads to exhaustion of the doping agent at the end which means unsupportive attitude of additive till to the end. This doesn't mean more mixing of additive will address this question because of higher release of unburned hydrocarbons in the tail pipe emissions. Since the viscosity and boiling point of DEE are far lesser than that of MME, faster dilution of DEE takes place in the dual fuel contingent mixture injected into combustion chamber. The injection throw distance for the DEE is obviously more than the biodiesel in the blend and hence DEE touches the combustion chamber walls earlier than the biodiesel and this might have been the reason for increase of hydrocarbons in the back drop of the increase of the DEE blend percentage. This worsening trend of higher HC emission is the reason, which limits higher blends of DEE along with biodiesel fuel.

3. EXPERIMENTATION

The experimental setup consists of the following equipment:

1. Single cylinder DI-diesel engine loaded with eddy current dynamometer
2. Engine Data Logger
3. Exhaust gas Analyzer
4. Smoke Analyzer
5. Vibration Analyzer

The Piezo electric transducer is fixed (flush in type) to the cylinder body (with water cooling adaptor) to record the pressure variations in the combustion chamber. Crank angle is measured using crank angle encoder. Exact TDC position is identified by the valve timing diagram and fixed with a sleek mark on the fly wheel and the same is used as a reference point for the encoder to with respect to which the signals of crank angle will be transmitted to the data logger.

The DI diesel engine (make Kirloskar company, Pune) is used for conducting the experimentation.

Table 2: Engine Specifications

Rated Horse power	:	5 hp (3.73 kW)
Rated Speed	:	1500rpm
No of Strokes	:	4
Mode of Injection	:	Direct Injection
Injection pressure	:	200 kg/cm^2
No of Cylinders	:	1
Stroke	:	110 mm
Bore	:	80 mm
Compression ratio	:	16.5

The experimentation is conducted (experimental set up shown in Fig.3) on the single cylinder direct injection diesel engine operated at normal room temperatures of 28^0C to 33^0C in the Department of Marine Engineering, Andhra University.

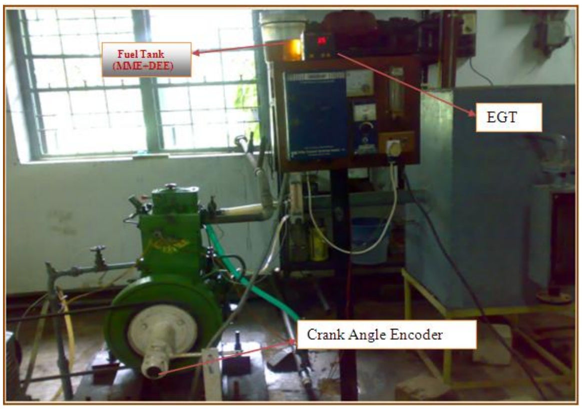

Fig.3 Experimental set up with accessories

The fuels used are diesel oil in neat condition and as well as methyl ester of Mahuva oil (MME) with 3%, 5%, 10%, and 15% additive Diethyl ether (DEE) and at five discrete part load conditions namely, No Load, One Fourth Full Load, Half Full Load, Three Fourth Full Load and Full Loads. The data collection is done independently for the above said oils. The engine is initially made to run at 1500rpm continuously for one hour in order to achieve the thermal equilibrium under operating conditions.

4. RESULTS & DISCUSSIONS

4.1 Cylinder pressure signature study

Combustion pressure values have been logged in the combustion cycle range of 720 degrees of crank revolution. The values have been logged at every one degree of crank angle interval. The combustion duration has effectively increased reducing peak pressure rise in the plots.

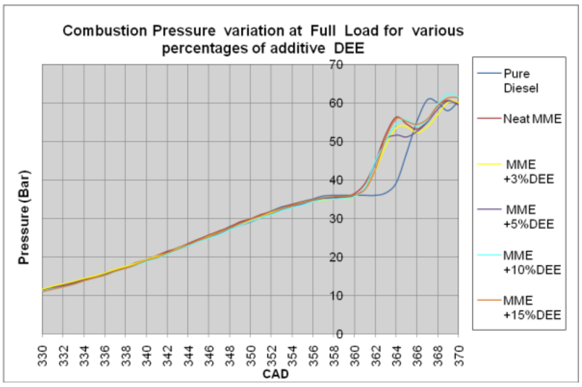

Fig.4 Close encounters of pressure plot to assess delay period variation

The delay period has increased insignificantly with respect to the increase in additive quantity in the blend as can be observed from the Figs 4 & 5. At full load, the delay period variation amounts to 3 degrees of crank revolution approximately (0.33ms) when compared to diesel fuel.

More the delay period means steeper the pressure rise leading to higher temperature combustion which can be surmised from the diesel pressure plot. 3% and 15% DEE percentages in the blend go hand in hand and 15% DEE blend supersedes the 3% DEE blend in diffused combustion zone hence recommending 15% DEE blend as a feasible one. There is a substantial improvement in the performance and emissions in the case 15% blend of biodiesel.

4.2 Heat release rate curves derived from the pressure signatures

Heat release in the acceleration mode of the piston is advantageous and that is what exactly is happening with the additive mixing. Even though, 3% additive mixing is going hand in hand in the combustion pressure generation, with 15% blend, as seen in Fig 4, there is an advantage of better diffused combustion on par with the neat biodiesel.

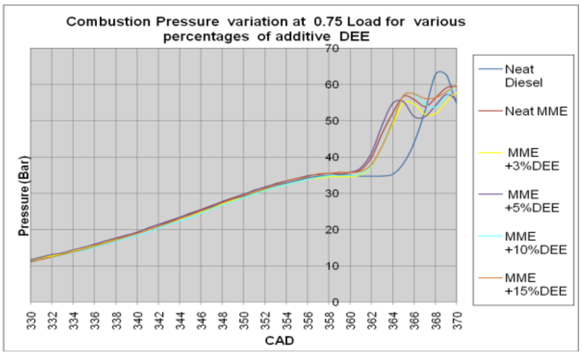

Fig.5 Close encounters of pressure plot to assess delay period variation

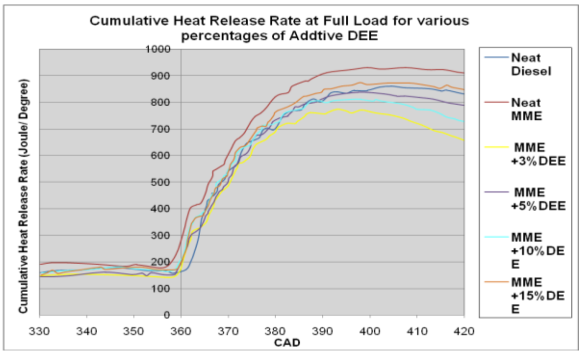

Fig.6 Cumulative heat release rate comparison with various percentages of Additive Diethyl Ether (DEE) along with Biodiesel at Full Load.

It can also be observed in the cumulative heat release curves in Figs. 6 and 7 in which later part of combustion curves are separated with greater drooping in the case of 3% additive mixing. At 3/4th full load, 15% DEE additive is more efficient in creating higher levels of cumulative heat release rate per degree when compared to other fuel configurations.

Initial burning rates are almost same in the case of 3% DEE and 15% DEE blends but end mixture burning rates are different with a maximum of 250 Joules per degree at 3/4th full load as shown in the Fig 7. Hence, 15% DEE blend is chosen as profitable blend with a vision focused on the performance and emissions also.

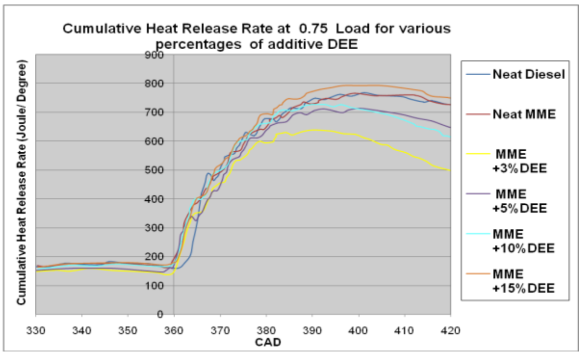

Fig.7 Cumulative heat release rate comparison with various percentages of Additive Diethyl Ether (DEE) along with Biodiesel at 3/4th Full Load.

4.3 Engine Performance

For every percentage of fuel mixing (MME+DEE) the density is calculated by using Redwood Viscometer and calorific value by using Bomb Calorimeter in our laboratory.

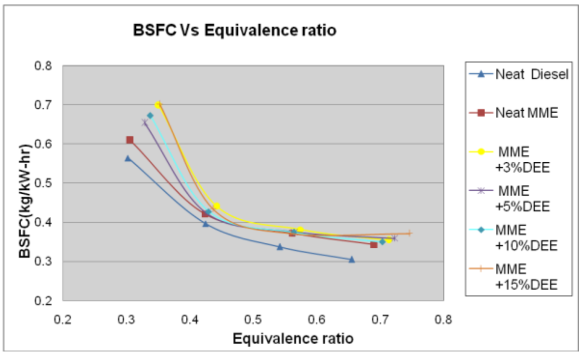

Fig.8 Brake Specific Fuel Consumption Vs Equivalence ratio graph with different percentages of additive Diethyl Ether (DEE)

The equivalence ratio at full load lies in between 6 and 7 for the diesel oil. This indicates that the engine is in good stead to conduct experimentation as shown in Fig 8. Biodiesel run engine maintains equivalence ratio of 7 at full load because the fuel consumption is more because of its lower heat value. In all other cases of additive blends, the equivalence ratio increases at full load. If compared 3% and 15% blends of DEE additive, 15% blend is more economical at part load performance of the engine approximately in between 0.4 and 0.65 equivalence ratios of the engine running it can be observed from the Fig 8. The brake specific fuel consumption increases from 0.3 kg/kW/hr to 0.375 kg/kW/hr when additive is being added with the defined blend percentages to the bio diesel. In the case of Neat biodiesel application, the BSFC stays at approximately 0.35 and with the additive percentages, it increases slightly, simultaneously increasing the equivalence ratio.

There is a steep rise of thermal efficiency for the additive percentages of '3' and '15' at part loads of the engine matching with the equivalence ratios 0.4 and 0.65 which can be observed from Fig. 9. For the additive blend 15%, the thermal efficiency stays at approximately 27% at full load. Even though the thermal efficiency suffers a little at full load, it is giving better at part load running of the engine

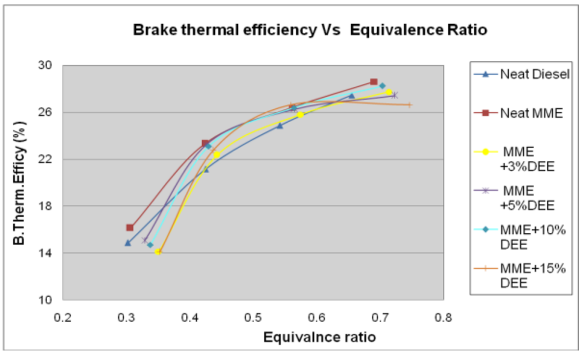

Fig.9 Brake Thermal Efficiency Vs Equivalence Ratio graph with different percentages of additive Diethyl Ether (DEE)

This steep rise may be due to better Cetane number and lower boiling point temperature of the additive. Better dilution with higher percentages of additive yielded better results but as the dope percentage is increasing, the emission of unburned hydrocarbons (HC) keep on increasing and this additive increase tells on the overall heat value of the blend.

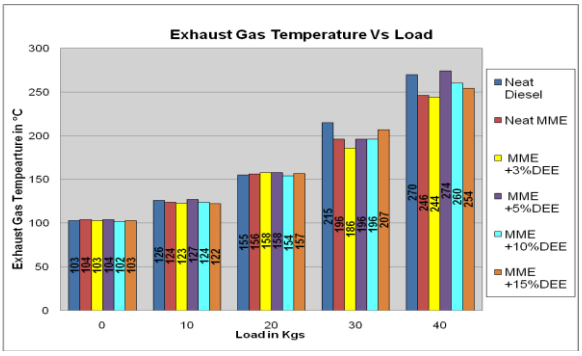

Fig.10 Exhaust Gas Temperature Vs Load Graph with different percentages of (DEE) along with Biodiesel at all loads.

Fig.10 envisages higher exhaust gas temperatures with 15% additive than at 3% indicating better diffused combustion as explained in the previous paragraphs.

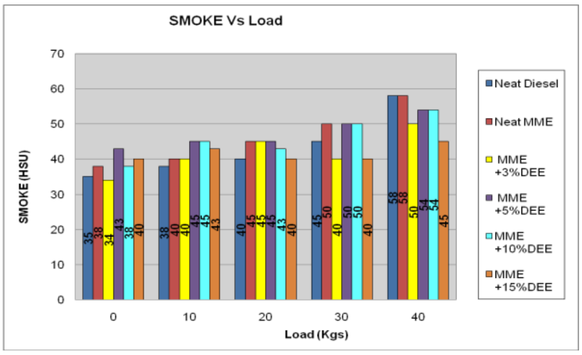

Fig.11 Smoke Vs Load Graph with different percentages of (DEE) along with Biodiesel at all loads

Fig.11 gives the smoke emission plot in HSU at various loads and at various additive percentages. Diesel Tune 114 smoke density tester is used to measure smoke and Delta Z-1600 L five gas analyzer is used to measure the emissions.15% of the DEE additive gives better smoke reduction indicating better combustion. There is a substantial 12% decrease in HSU in the case of 15% DEE blend and with a consistent relative lower levels of smoke at all other part loads.

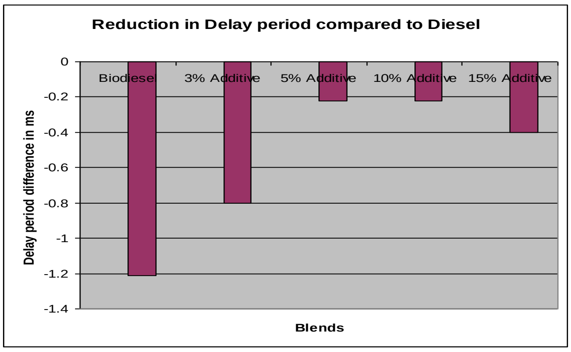

Fig.12 Delay period difference in milliseconds w.r.t. Diesel at full load.

The delay period difference, as shown in Fig.12 is plotted with respect to the petro diesel and is derived from time waves of vibration at full load recorded on the cylinder head in vertical direction.

For Biodiesel the delay period decreased by 1.21 ms and the decrease in delay period is reducing w.r.t the additive blend. At 5% additive blend, the decrement is minimum and there upon it is increasing since cold combustion is taking place with respect to increase in additive.

5. CONCLUSIONS

1. The additive DEE and the main biodiesel are possessing nearer densities and the blend 15 % is also observed to be stable during engine operation over limited hours observed in the laboratory.
2. 15% DEE blend with biodiesel is adjudged as the best combination which yielded better results than other fuel blends tested especially 3% blend which is the nearest competitor.
3. 3% and 15% blends create delay period difference of 0.4 ms (lesser for 15% blend) which can be observed from the real time, time wave plots at full load. But in the case of 15% blend, the diffused combustion aspect is very much improved.
4. The thermal efficiency rise and SFC are better in the case of 15% additive blend and since diesel engines give better efficiency at part loads this percentage of blend can be recommended.
5. The equivalence ratio at full load in the case of the two blends differ marginally, 15% blend can be adopted for the reason the difference is significantly small and there won't be much larger loss of fuel at little higher equivalence ratio.
6. The cumulative heat release rate plot of 15% DEE blend is better at part load i.e. at $3/4^{th}$ full load and is overriding all plots with lower DEE percentages indicating that the combustion with this percentage is better both in premixed combustion zone and diffused zone. And at full load, the 15% DEE blend occupies second position next to the neat biodiesel application while all other blends are lagging behind.
7. The smoke levels have decreased substantially with 15% DEE blend with biodiesel at full load and at immediate part load except very low loads at which the diesel engine may not be put to operation normally because of high *bsfc*. Smoke levels have decreased in tandem indicating better combustion

REFERENCES

1. Bennet hum, J. and Winsor, R, 1991, "Toward Improved Diesel Fuel," Society Of Automotive Engineers Technical Paper 912325, doi:10.4271/912325.
2. Graboski, M., Ross, J., and McCormick, R, 1996, "Transient Emissions from No. 2 Diesel and Biodiesel Blends in a DDC Series 60 Engine," Society Of Automotive Engineers Technical Paper 961166, doi:10.4271/961166.
3. Liotta, F. and Montalvo, D, 1993, "The Effect of Oxygenated Fuels on Emissions from a Modern Heavy-Duty Diesel Engine," Society Of Automotive Engineers Technical Paper 932734, doi:10.4271/932734.
4. Nikanjam, M, 1993, "Development of the First CARB Certified California Alternative Diesel Fuel," Society Of Automotive Engineers Technical Paper 930728, doi:10.4271/930728.

5. Ullman, T., Spreen, K., and Mason, R, 1994, "Effects of Cetane Number, Cetane Improver, Aromatics, and Oxygenates on 1994 Heavy-Duty Diesel Engine Emissions," Society Of Automotive Engineers Technical Paper 941020, doi:10.4271/941020.
6. McDonald, J., Purcell, D., McClure, B., and Kittelson, D 1995, "Emissions Characteristics of Soy Methyl Ester Fuels in an IDI Compression Ignition Engine," Society Of Automotive Engineers Technical Paper 950400, doi:10.4271/950400
7. Iranmanesh, M., Subrahmanyam, JP. and Babu, MKJ., 2008, “Potential of Diethyl ether as supplementary fuel to improve combustion and emission characteristics of diesel engines”, Society Of Automotive Engineers paper no. 2008-28-0044.
8. Kaplan, N., Mohanan, P. and Reddy, RP., 2008,“Performance and Emission studies of Diesel Engine Using Diethyl Ether as Oxygenated Fuel Additive”, Society Of Automotive Engineers paper no. 2008-01-2466.
9. Yeh, LI., Rickeard, DJ., Duff, JLC., Bateman, JR., Schlosberg, RH. and Caers, RF, 2001, “Oxygenates: An Evaluation of their Effects on Diesel Emissions”, Society Of Automotive Engineers paper no. 2001-01-2019.

NOMENCLATURE

Symbol

DI	Direct Injection
PM	Particular Matter
DEE	Diethyl Ether
HC	Hydro Carbon
HSU	Hartridge Smoke Unit
MME	Mahuva Methyl Ester
RT	Room Temperature
NO_x	Nitrogen Oxide

AUTHOR BIOGRAPHY

Mr.P.Ramesh Babu is an Assosiate Professor at Department of Mechanical Engineering at GMR Institute of Technology,Rajam, India. He has 10 years of teaching experience. He has research interst in alternate fuels, heat transfer, clean coal energy, engine combustion etc. He has several publications in various national and international journals.

Dr.V.Ram Babu is an Assosiate Professor and Head of the Department of Mechanical Engineering at GMR Institute of Technology,Rajam, India. He has 14 years of teaching experience. He has research interst in alternate fuels, heat transfer, clean coal energy, engine combustion and gasifications etc. He has several publications in various national and international journals.

Mr.S.Ravi Babu is an Assistant Professor at Department of Mechanical Engineering at GMR Institute of Technology,Rajam, India. He has 8 years of teaching experience and 4 years of industry experience. He has research interst in heat transfer, clean coal energy, engine combustion etc. He has several publications in various national and international journals.