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Combustion Heat Release Estimation to Explore Best Blend of Mahuva Methyl Ester and Diethyl Ether as Cetane Improver

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Abstract

Single zone heat release rate calculations with in cylinder heat transfer are done with the combustion pressure as an input and a comparative study is taken up with neat diesel and Mahuva methyl ester as a biodiesel with Diethyl Ether (DEE-Cetane improver). Combustion Delay period trend is assessed by the close scrutiny of the combustion pressure signatures and the combustion behavior is being assessed with the net heat release rate and cumulative heat release plots at various loads on the engine with different fuels. Present work deals with trials of Mahuva Methyl Ester (MME) and Diethyl Ether (DEE) additive blends. Various blends of MME with additive at different percentages (3%, 5%, 10%, and 15%) by volume were prepared and tested in full range of engine load. Results obtained from the study shows that 15% of additive with MME could be a better fuel in terms of combustion pressure changes and heat release. Further, the blend can be used in any existing CI engines without engine modification or fuel preheating. Mixing DEE additive with biodiesel improves the cold flow, combustion efficiency, and viscosity and reduces the engine detonation. Combustion analysis is also taken up with real vibration time waves recorded vertical on the cylinder head.

Key words: *Biodiesel, additive, Diethyl Ether, MME, Delay period, Combustion analysis.*

1. Introduction

The need for searching of alternate fuel is increasing day by day due to fast depletion of fossil fuel sources. To decrease the dependency on diesel, biodiesel fuels (BDF) are the best choice as an alternate future fuels. Biodiesels can be used directly in diesel engines without any modifications [1]. BDF offers the following benefits as it is non-toxic, biodegradable, essentially free of sulfur and carcinogenic benzene, and reduces air pollution. These are derived from renewable and recycled resources, which do not significantly add to the greenhouse effect-gas accumulation as associated with petroleum derived fuels. As biodiesel fuels are oxygenated, they have a higher flash point. The use of BDF has more advantages in CI engines such as clean burning fuel, being safer to handle and store than petroleum diesel [2-5].

The literature survey reveals that using fuel additives, which are oxygenated in nature, reduces the emissions. In these oxygenates, ethers behave better than alcohols. Extensive experiments were conducted by Tadashi Murayama et-al [6] on a low emission DI diesel engine by using Di-methyl Carbonate (DMC) as an oxygenate fuel additive. The results indicated that smoke reduced almost linearly with fuel oxygen content. Theodore Constantine Zannis et-al [7] observed that decrease of ignition delay with increasing oxygen content, following thus the increase of cetane number. A considerable reduction of soot, carbon monoxide and unburned hydrocarbon emissions were witnessed while nitric monoxide emissions increased when the oxygen content increased from 3% to 9% by the addition of oxygenated additives. Oxygenated additives have been considered for reducing the ignition temperature of particulates. However, the reduction of particulate emissions through the introduction of oxygenated compounds depends on the molecular structure and oxygen content of the fuel and also depends on the local oxygen concentration in the fuel plume [8]. To reduce particulate emissions, fuel-compatible oxygen-bearing compounds should be blended with diesel to produce a composite fuel containing 10-25% v/v of oxygenate.

Therefore, the composition of diesel and the use of additives directly affect properties such as density, viscosity, volatility, behavior at low temperatures, and the Cetane number. Song, K. Het.al showed that the ignition temperature of particulates from seed-derived oils (SO) and from blends of SO with diesel fuel (DF) can be lower

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than that of particulate from neat Diesel Fuel [9]. S. Sivalakshmi et.al showed betterment in performance with 15% DEE blended with JOME and this performance deals with fuel consumption, thermal efficiency, and emissions [10]. R.G. Abtonini reported on DEE as a new option for diesel engine fuels. This paper defends the use of DEE as an option for diesel engines mixed with vegetable oils or diesel fuel. Alcohol can be converted into DEE by dehydration with solid fixed bed catalyst. DEE's advantage over ethanol include its non-corrosive nature and its greater heating value. It can be mixed with any biodiesel or diesel [11].

In this attempt, a study is being conducted to assess the heat release rate during combustion related to premixed and diffused combustion and a comparison is made with neat diesel combustion to explore advantages with the new fuel combinations using biodiesel as the main fuel and DEE as the oxygenated additive. Apparent heat release model has been developed by Krieger and Boreman and the same is employed here to calculate the Net heat release rate[12] and in the cylinder heat transfer is calculated using the theory developed by Annand and Ma T [13] with the assumptions for diesel engine application [14].

Fuel combustion behavior is assessed from the vibration time wave signatures recorded on the cylinder head and with the assistance of combustion pressure signatures.

2.0 Theory of heat release rate calculations

$$\frac{dQ_n}{d\theta} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dp}{d\theta},$$

$$\frac{C_p}{C_v} = \gamma, R = C_p - C_v$$

The gas temperature can be found from the equation of state ($pV=mRT$), since the pressure and volume are known, and it has been assumed mass is constant. The gas properties vary with temperature, but the variation is modest, It is acceptable in most cases to evaluate the properties at the gas temperature computed in the previous increment. Equations below can be used to evaluate the properties u and R, from which 'γ' can be evaluated. Once the gas temperature has been evaluated, it is possible to estimate the heat transfer, by assuming wall temperature and employing a heat transfer correlation.

An approach was adopted by Krieger and Borman [12], who provided polynomial coefficients from the curve fit to combustion problem calculations for weak mixtures ($\phi \leq 1$) of C_nH_{2n} with air.

$$u = K_1(T) - K_2 T\phi \, kJ/kg \, of \, original \, air$$

Where

$$K_1 = 0.692T + 39.17\times10^{-6}T^2 + 52.9\times10^{-9}T^3 - 228.62\times10^{-13}T^4 + 277.58\times10^{-17}T^5$$

$K_2 = 3049.33 - 5.7 \times 10^{-2}T - 9.5 \times 10^{-5}T_2 + 21.53 \times 10^{-9}T^3 - 200.26 \times 10^{-14}T^4$

With gas constant given by

$$R = 0.287 + 0.020\phi \, kJ/kg \, of \, original \, air/K$$

2.1. In cylinder heat transfer

Annand and Ma [13] have developed the equation with the inclusion of radiation heat transfer:

$$\frac{Q_s}{A_s} = c\frac{k}{B}\mathrm{Re}^b (T - T_s) + d(T^4 - T_s^4)$$

And for a compression ignition engine Watson and Janota [14] suggested:

$$b = 0.7$$
$$0.25 < c < 0.8$$
$$d = 0.576\sigma$$

σ = Stefan- Boltzmann constant.

3.0. Experimentation

Four stroke single cylinder DI diesel engine test rig as shown in Figure. 1 of rated power 3.72 kW at 1500rpm, cylinder diameter 80mm, Stroke length 110mm and compression ratio 16.5:1 with eddy current dynamometer as loading devise is being used. Experiments were conducted with neat diesel, neat MME and MME blended with Diethyl Ethyl Ether additive at different percentages for full load range of the engine. Cylinder combustion pressures at each degree of crank angle are measured by engine data logger and the software C7112 is used to integrate the crank angle and corresponding pressure values to draw plots. Net heat release rate and cumulative heat release rates based on Krieger and Boreman [12] and in cylinder heat transfer based on Annand and Ma [31] are computed and plotted to compare for all experiments at same load. Specific comparison is taken up with the diesel fuel and its heat release.

DC-11 vibration analyzer is used to measure the cylinder vibration real-time time and amplitude signatures to correlate the pressure and vibration variation at different loads. The firing zone has been selected with TDP position identification for the pressure- time wave comparison.

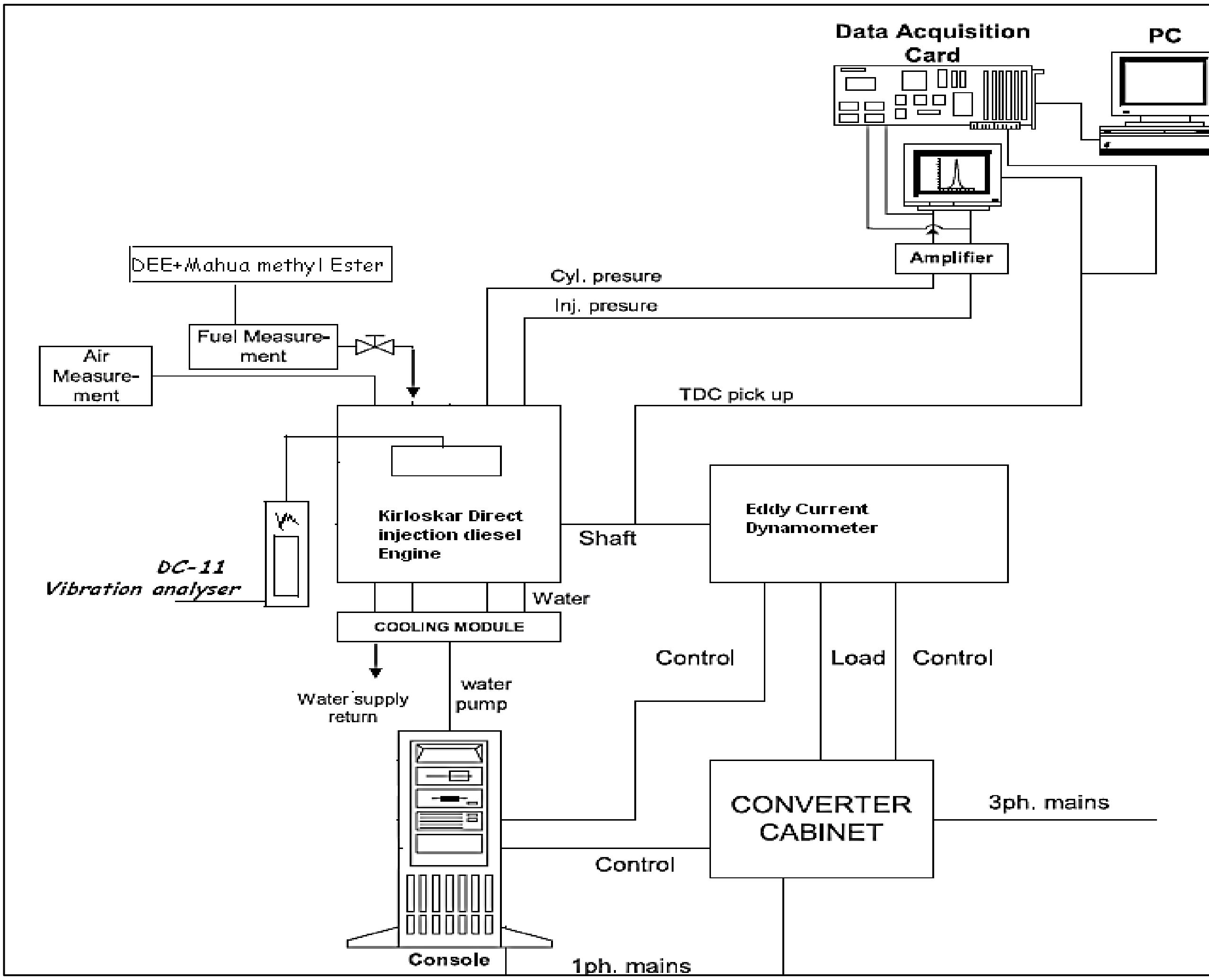

Fig. 1 Schematic Diagram representing of the engine and instrumentation

4.0 Results and discussion

Combustion pressure and vibration time waves were measured for diesel, MME and MME with DEE additive blends without modifications in the engine (Figures (2) to (5). Heat release rate and cumulative heat release rate were computed using the modeling described in article 2.0 (Figures from (2) to (9). The time waves were recorded on the cylinder head and the wave form in the explosion stroke is isolated and represented against pressure signature to study the inner details of combustion (Figures from (10) to (16)). With more DEE in the blend, the specific heat of the blend decreased and as a consequence the sensible heat absorption has also decreased per degree rise of temperature. Hence, leading to progressively higher cumulative heat release rate as can be observed from Figures (6) to (9). It can be observed better diffused combustion with the increase in the DEE percentage because faster is the blend reaching auto ignition temperature.

There is a rapid fall of heat release in the case of 5% DEE blend in the diffused combustion zone at both full load and three fourth full load of the engine. 15% DEE blend exhibited better combustion performance all through the two zones of combustion viz. premixed and defused combustion zones and there by the Indicated mean effective pressure is maximum to the tune of 7.7 bar at full load running of the engine comparatively. Figures from (10) to (16) represent the individual and comparative graphs of time waves and pressure plots for all combinations of the blends and neat fuels. Figure 16 includes the vibration time wave and pressure signature belonging to 15% DEE blend in comparison with neat diesel and bio-diesel operations. This envisages nearly harmonic variation of cylinder vibration with no mix up of frequencies originating from the combustion excitation. This means the combustion is smoother than other combinations. Table.1. demonstrate the properties DEE and Table No.2 include pressure parameter variations and the power generated. 1.06 ms start of combustion before TDC Recorded for 15% DEE emulsion.

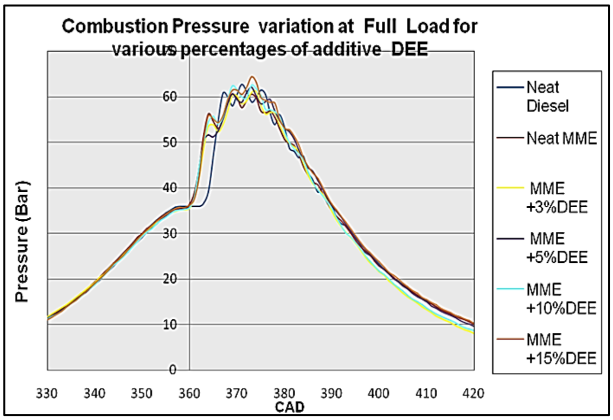

Fig.2 Variation of pressure verses crank angle of engine at full load

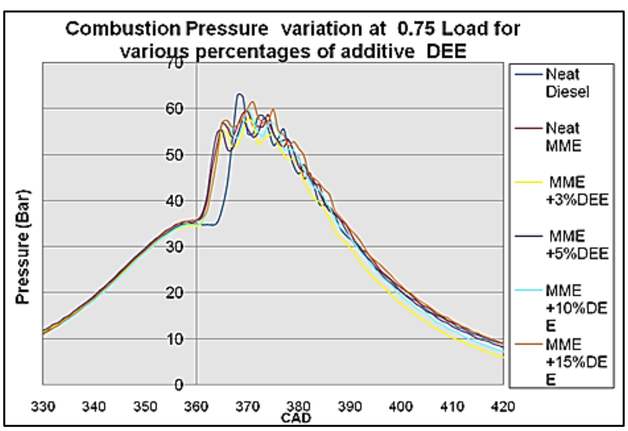

Fig.3 Variation of pressure verses crank angle of engine at 75% full load

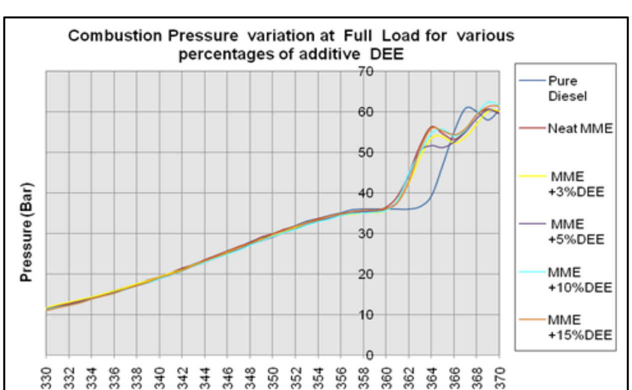

Fig.4 Variation of delay period plot of engine at full load

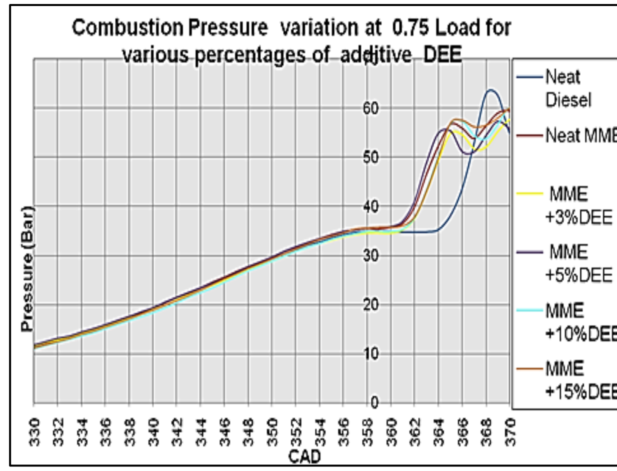

Fig.5 Variation of delay period plot of engine at 75% full load

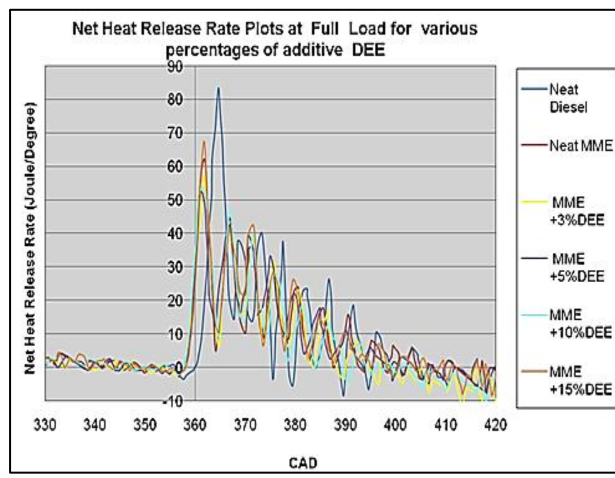

Fig.6 Variation of net heat release rate verses crank angle of engine at full load

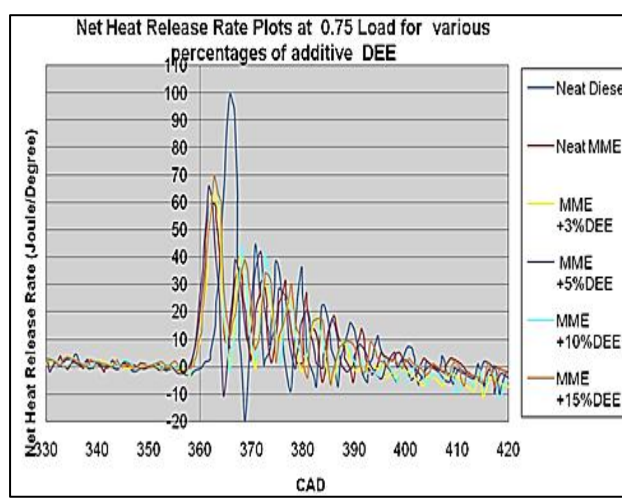

Fig.7 Variation of net heat release rate verses crank angle at 75% full load

Table1 Important Properties of Diethyl ether

Chemical Structure	C_2H_5-O- C_2H_5
Specific Gravity	0.713
Viscosity mm^2/sec (20^oC)	0.23
Auto ignition point (^oC)	160
Lower Heating Value (kJ/kg)	33900
Cetane Number	>125
Flammability limit (% Vol)	Rich 9.5 to 36
Oxygen content (by % wt)	21
Boiling point(^oC)	35
Stoichiometric A/F Ratio	11.1
Latent Heat of Vaporization(kJ/kg)	356
Calorific value (kJ/kg)	33900

Table2 Full load combustion Parameters

S.No	Fuel	Indiacted Power (kW)	IMEP (bar)	Peak pressure (bar)	Position of peak pressure w.r.t.to TDP (Deg)	Max. Differential pressure (bar)
1	Diesel	5.18	7.5	62.7	+10	7.6
2	Biodiesel(MME)	5.3	7.3	60.7	+8	6.2
3	3%DEE+ MME	3.88	5.6	61.1	+12	5.4
4	5%DEE+ MME	4.90	7.1	62.1	+12	5.5
5	10%DEE+ MME	4.34	6.3	62.6	+12	5.6
6	15%DEE+ MME	5.31	7.7	64.4	+12	6.5

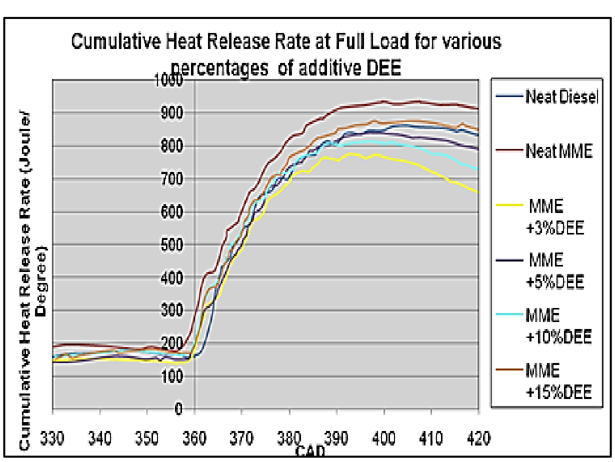

Fig.8Variation of cumulative heat release rate verses crank angle of engine at full load

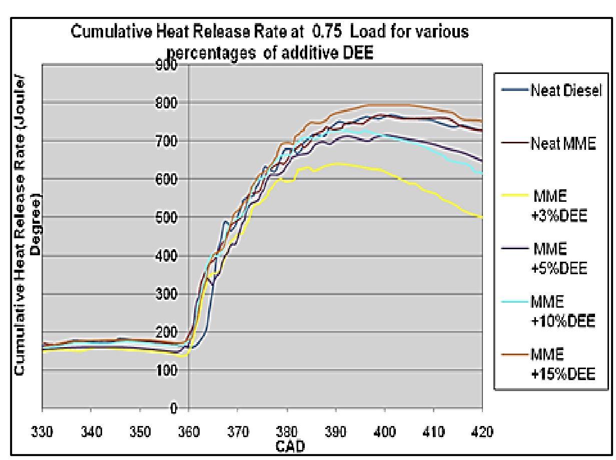

Fig.9Variation of cumulative heat release rate verses crank angle at 75% full load

Conclusion

With the increase of percentage of DEE in the biodiesel, the specific heat of the blend is decreasing with lesser latent heat and thereby absorbing more heat from the compressed gases to reach the auto ignition temperature faster.

The cetane number of the additive is more than125. The blend with the biodiesel may not increase the overal cetane number as per the previous works.

It can be observed better diffused combustion with the increase in the DEE percentage because faster is the blend reaching auto ignition temperature.

15% DEE blend exhibited better combustion performance all through the two zones of combustion viz. premixed and defused combustion zones and there by the Indicated mean effective pressure is maximum to the tune of 7.7 bar at full load running of the engine comparatively.

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