https://dx.doi.org/10.22161/ijaers.5.9.28 ISSN: 2349-6495(P) | 2456-1908(O)

Role of Triacetin additive in the performance of single cylinder D I diesel engine with COME biodiesel

P. Venkateswara Rao

Professor, Department of Mechanical Engineering, Kakatiya Institute of Technology & Science, Warangal-506015, Telangana, India

pvrao.kits@gmail.com

Abstract**—*In the present work, COME-Triacetin additive blends are experimented in lieu of the neat diesel fuel. Pure coconut oil methyl ester (COME) itself as an additive has advantages in the operation of engine. Attention is bestowed upon the reduction of HC, NO, CO_2, CO and smoke emissions, and the same is successfully achieved with the 10% Triacetin and 90% COME blend fuel. Vibration on the engine cylinder in three directions and on the foundation were measured and analyzed to elicit information about the nature of combustion. The pressure signatures are tallied with time waves eliminating the time lag in between exciter and the cylinder head vibration. Triacetin being an antiknock fuel, with 10% blend emanated as a best blend with its contribution to reduce cylinder vibration in vertical direction of the cylinder. The time wave resembles attenuated sine wave replete with pure harmonics indicating smoother combustion with lesser engine detonation. By analyzing the measured in-cylinder pressure data and the derived heat release rate, it is concluded that the addition of triacetin increases the ignition delay and the amount of heat release in the premixed combustion duration, but shortens both the diffusive burning duration and total combustion duration. On the emission side, the smoke and other emissions including NO are reduced without any cognizable trade off with other components of the emissions.*

Keywords—Performance, emissions, Biodiesel, Triacetin, Additive, Blend fuels, Properties, Vibrations, Heat release rate, Blend fuel.

I. INTRODUCTION

The price hike and rapid depletion of fossil fuels make researchers to concentrate on search for alternative fuels. Methanol and ethanol are proved to be effective alternative fuels long ago for internal combustion (IC) engines. The oxygen in the methanol and ethanol molecules helps to make complete combustion when combusted with atmospheric oxygen. Most recently noticed that DME with oxygen content of 34.7% by weight is one of the promising alternative fuels for IC engines. DME can be derived from natural gas, coal or even from biomass sources that decreases emissions including smoke, THC, carbon dioxide, NOx, while slight increase in CO compared to those of conventional diesel fuel [**1**]. Lower smoke and THC emissions were reported 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 and lower NOx emissions with DEE-diesel blends [**2**]. From the experiments with 5 % DEE found lower CO, THC and smoke emissions while a slight improvement in thermal efficiency was observed [**3**].

Biodiesel obtained by the transesterification of oils or fats from plants or animals, with short-chain alcohols such as methanol and ethanol can be used pure or blended with diesel [4]. Biodiesel is nonflammable, non-explosive, biodegradable, nontoxic, its usage provide reduction of many harmful exhaust emissions and nearly complete absence of sulfur oxide (SO_x) emissions, particulate and soot [**5**]. Reduction of CO2, CO, HC, NO, and smoke emissions were achieved successfully with 10% Triacetin and 90% COME blend fuel. Triacetin, being an antiknock fuel with 10% blend fuel, emanated as the best blend fuel with its contribution to reduce cylinder vibration in the vertical direction. By analyzing in-cylinder pressure data and released heat rate, it is observed that the addition of Triacetin increases the ignition delay and the amount of heat release in the premixed combustion duration, but shortens both the diffusive burning duration and hence total combustion duration [**6**]. Knocking can be prevented by the addition of additives in biodiesel fuel. Triacetin additive can be used as an antiknock agent to reduce engine knocking, to improve cold flow and viscosity properties of biodiesel [**7**]. In case of biodiesel-diesel blends the performance of engine increased appreciably with less BSFC for blend fuel and CO, HC, NOx emissions and smoke density reduces significantly but a slight increase in CO_2 as the compression ratio increases [**8**]. The mixture of fuel and additive provides a stable film on the metal surface and substantially reduces the wear scar on the surface area[**9**].Fatty compounds possess better lubricity than hydrocarbons because of their polarity-imparting oxygen atoms [**10**]. A high cetane number leads to a reduction of both exhaust and NOx emission [**11**].

Clean combustion of diesel engines can be fulfilled only if engine development is coupled with diesel fuel reformulation or additive introduction [**12**].High-pressure injection, turbo charging, and exhaust after treatments or the use of fuel additives, which are thought to be one of the most attractive solutions to reduce PM and NOx emissions [**13**]. The B20 blend fuel with alcohols viscosity and density, cetane number and acid values decrease as the percentage of alcohol increases. Alcohols lower the flash point slightly and reduce the viscosity and density of blend fuel marginally, with this fuel ignition can start at lower temperature and able to burn completely [**14**]. The fuel properties can be adjusted by blending diesel with clean biodiesel to improve performance with less pollutant emissions from engines. Biodiesel is miscible with diesel fuel and can be mixed in any proportion to burn in diesel engines with no major modifications of the engine [**15**]. Further the biodiesel is easily biodegradability; lubricate the engine parts, lowers greenhouse gas emissions and more efficient in combustion levels [**16**]. Hence, biodiesel could be a most reliable alternative fuel for emissions reduction in diesel engine applications. Vegetable oils such as rapeseed, soybean and palm oil, algae oil and animal fats which are primarily composed of triglycerides, are used to produce biodiesel, is also known as fatty acids methyl ester.

In this work Triacetin additive chosen to conduct the experiments with coconut oil methyl ester (COME) because the main advantage of this additive is easily soluble in biodiesel, suppress the knocking of engine, improve efficiency and reduce the tail pipe emissions. Triacetin additive at various percentages with COME (by volume) blends are used to study the properties of blend fuels and performance, exhaust gas analysis, smoke density and vibrations of engine.

II. PREPARATION OF BIODIESEL

Initially raw Coconut oil is filtered and heated up to 105^{0}C temperature in order to remove solid particles and water content. In acid treatment methanol of 120ml and 2ml of concentrated highly pure H_2SO_4 per liter of oil is added and heated with magnetic stirrer at 60^{0}C for about half an hour in a closed conical flask. The mixture is allowed to settle down in a decanter. The settled glycerin is separated at bottom of decanter from methyl ester. *Sodium Methoxide* is prepared by mixing thoroughly 200ml of methanol (20% by vol.) with 6.5 grams of NaOH per liter of oil. This solution is added to the oil obtained from acid treatment, then stirred continuously at 62^{0}C for one hour in the base treatment and allowed to settle down in decanter. The collected Coconut oil methyl ester (COME) is bubble washed with pure water in order to remove soap contents, acid and methanol. The washed COME is heated further above 100^{0}C for some time to remove water content [**17**], [**18**]and the different stages of biodiesel making and prepared biodiesel are shown in Figs. **1** and **2**. The proportions of biodiesel along with Tiacetin additive blends fuels shown in table 1 were prepared to find properties and performance of diesel engine.

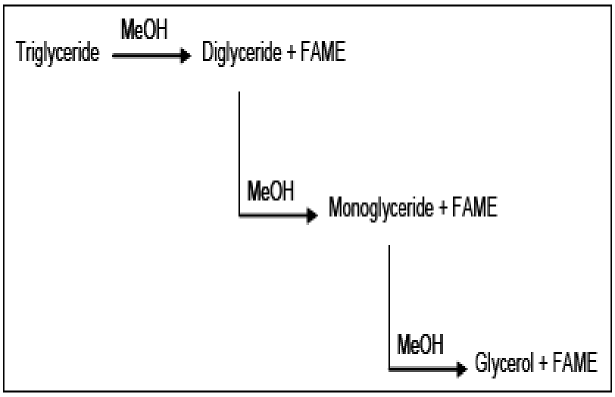

Fig.1: Stages of Biodiesel (COME) preparations

Fig. 2: Final stage of (Heating) Biodiesel

Table 1: Blend fuels for Test

S. No	Type of Fuel	Percentages in Blend Fuel
1	Diesel	100% Diesel
2	BD100	100% Biodiesel (BD)
3	BD5T	95%BDl+ 5%Triacetin(T)
4	BD10T	90%BD+10%Triacetin
5	BD15T	85%BD+15%Triacetin
6	BD20T	80%BD+20%Triacetin
7	BD25T	75%BD+25%Triacetin

https://dx.doi.org/10.22161/ijaers.5.9.28 ISSN: 2349-6495(P) | 2456-1908(O)

III. EXPERIMENTATION PROCEDURE

The experiments were conducted on a single cylinder DI diesel engine operated at normal room temperatures of

28^0C to 33^0C. Coconut oil methyl ester **(COME)** was prepared in Fuels Laboratory by transesterification process. Dual fuel (blends) operation of **COME** with Triacetin additive is taken up as an alternative fuel for testing at five different percentages (5%, 10%, 15%, 20%, and 25%) by volume. Neat diesel oil and pure biodiesel are also implemented at five discrete part load conditions to enable for comparison. Experimentation were carried out at various engine loads at 1500 rpm (Engine Loading device is eddy current dynamometer) to record the cylinder pressure and to compute heat release rates with respect to the crank-angle. Engine performance data is acquired to study the above mentioned parameters along with engine cylinder vibration and engine pollution parameters. Engine cylinder vibration in FFT form is monitored at each load for COME and its blends simultaneously to compare the cylinder excitation frequencies with the base line frequencies using diesel oil. Time wave forms on the cylinder head are also recorded to analyze the combustion for heat release rates. Since the combustion in the cylinder is the basic exciter, the vibration study of the engine cylinder is measured through FFT and time waveforms. These factors are the representatives of combustion propensity. The smoke values in HSU and exhaust gas analysis of different constituents of exhaust are measured and compared with diesel fuel.

IV. RESULTS AND DISCUSSIONS

Experiments were conducted with neat petro diesel, COME and COME-Triacetin **[$C_9H_{14}O_6$]** additive blends at 5%, 10%, 15%, 20% and 25% by volume on DI diesel engine without modifications in the engine operating parameters. The engine general performance, combustion, emissions and engine vibration results are compared with neat diesel and the results are summarized as follows:

4.1 FUEL PROPERTIES: The properties of fuels provide important data to further investigate and analyze the engine operation in terms of performance, combustion and emission characteristics and compare the same with diesel fuel.

4.1.1 Viscosity: Biodiesel viscosity is higher as compared to diesel fuel to use diesel engine, but it can be used as a substitute to diesel fuel at lower viscosity with minimum environmental pollution. Under low temperatures viscosity has a greater impact on fuel to flow smoothly from the storage tank into the engine. Higher viscosity causes poor atomization of the fuel spray system and inaccurate fuel injectors operation causes improper combustion in the engine cylinder, results increased exhaust smoke and emissions. From the figure **3** it is observed that the viscosity of biodiesel is 26.5% more than diesel fuel because of free fatty acid (FFA) concentration in biodiesel. Due to higher viscosity of biodiesel and triacetin, the blend fuels of biodiesel with triacetin also at higher viscosity than diesel fuel. On other hand, small amount of triacetin addition in biodiesel increases the viscosity of blend fuels (5%, 10%, 15%, 20% and 25%) by 0.27%, 0.34%, 0.41%, 0.49% and 0.6% in comparison with biodiesel, which is within the limits of diesel fuel.

4.1.2 Heating value: The amount of heat energy released by the combustion of a unit value of fuel is known as heating value of the fuel. One of the most important constituent that vary the heating value in the fuel is moisture content. The heating value is not specified in the biodiesel standards ASTM D6751 and EN 14214 but is prescribed in EN 14213 (biodiesel for heating purpose) with a minimum of 35 MJ/kg. Figure 4 shows that the heating values of neat petro diesel, COME and COME-Triacetin **[$C_9H_{14}O_6$]** additive blends at 5%, 10%, 15%, 20% and 25% by volume are gradually decreasing. Heating value decreases as the percentage of triacetin increases in the blend fuel because the heating value of triacetin (16MJ) is much less than biodiesel (36MJ). A minimum heating value obtained for 25% of triacetin additive with biodiesel (BD25T) was 32 MJ/kg, which is 11.12% less than the heating value of biodiesel used for testing. The heating values of all blend fuels are within the requirement of standards.

4.1.3 Density:The density of biodiesel is higher than diesel fuel. Biodiesels density can be improved with the addition of additives for better performance of the engine. The density is measured by using Portable Density/Gravity Meter. High viscosity of fuel leads to problem in pumping and spray characteristics such as atomization, penetration and combustion etc. The improper mixing of fuel with air contributes to incomplete combustion that leads to low power output and exhaust with pollutants. Figure **5** shows the density of diesel, biodiesel and biodiesel with triacetin blend fuels. It is observed that the density of biodiesel is the higher at 0.892 kg/m^3 and density of diesel is the lower at 0.857 kg/m^3. The removal of the glycerol from vegetable oil has significantly reduced the density biodiesel fuel and it is 3.92% higher than diesel fuel. Increase in triacetin percentage in biodiesel increases the density of blend fuel, but which has very similar density values as conventional diesel fuel.

https://dx.doi.org/10.22161/ijaers.5.9.28 **ISSN: 2349-6495(P) | 2456-1908(O)**

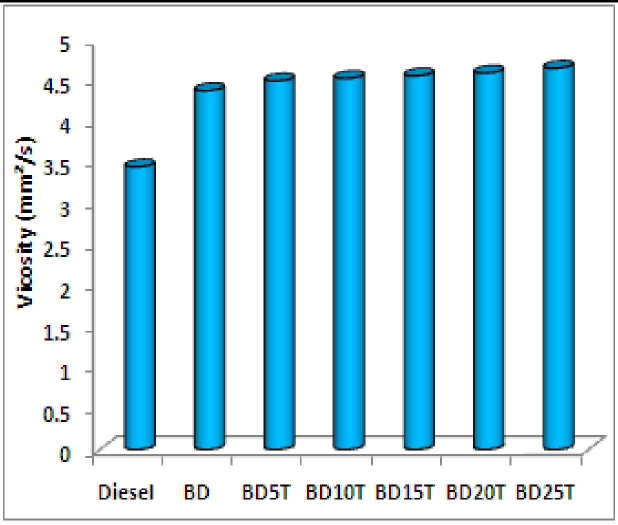

Fig.3: Viscosity values of Test fuels

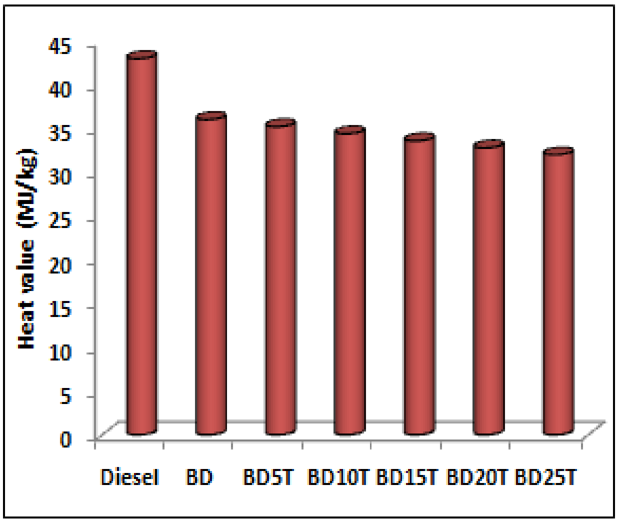

Fig.4: Heat values of Test fuels

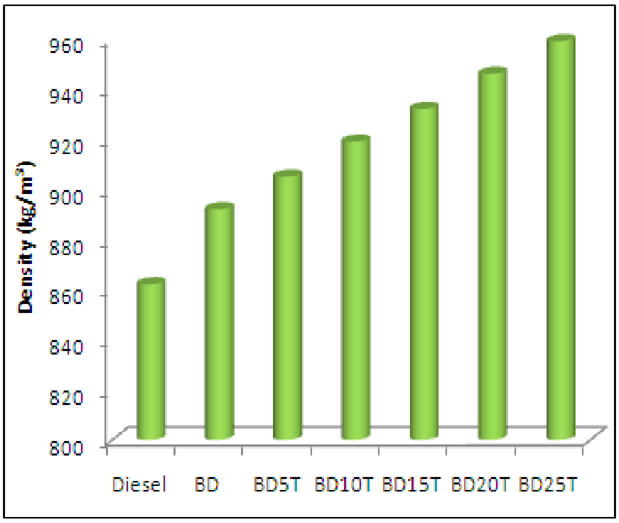

Fig.5: Density values of Test fuels

4.2 HEAT RELEASE RATE: The cumulative and net heat release rate graphs at full load are shown from figures **6** and **7**. It can be observed that the net heat release rate peak is increasing with the increase of triacetin in the blend fuel. The 10% Triacetin blend falls in between the diesel and biodiesel in the net and cumulative heat release rate aspects and emerges as the best alternative to the conventional diesel fuel. The cumulative heat release rate graphs decipher consistent performance both in the premixed and diffused combustion zones for 10% triacetin blend fuel with biodiesel. The 5% triacetin joins the band wagon of 20% and 25% triacetin blend fuels with respect to the low profile diffused combustion. From the figure **8** the observation is that maximum cumulative heat released at full load and net heat release are less due to more heat transfer to cylinder surface at that load, as compared to 75% load on the engine.

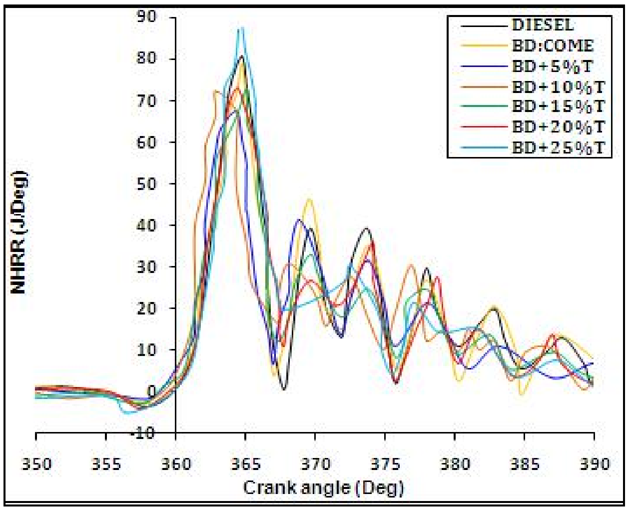

Fig. 6: NHRR vs Crank Angle at Full Load

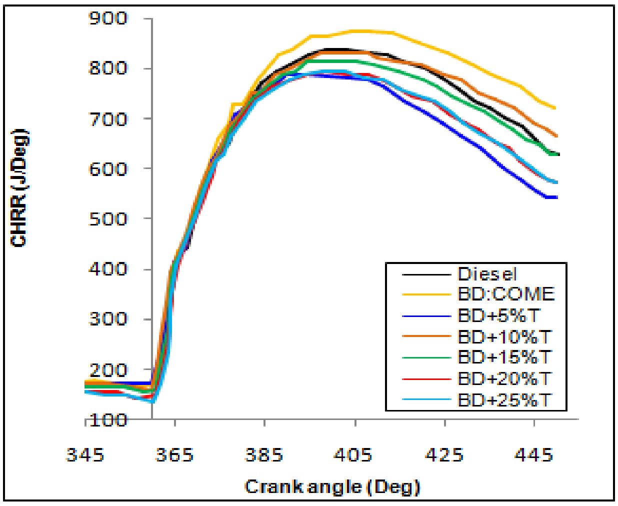

Fig. 7: CHRR vs Crank Angle at Full Load

https://dx.doi.org/10.22161/ijaers.5.9.28 *ISSN: 2349-6495(P) | 2456-1908(O)*

In the case of 10% triacetin blend fuel, the ignition delay is decreased, as this blend fuel is optimal in reducing vibrations and to improve combustion quality of engine. Heat release rate curves indicates better performance in case of 10% triacetin blend fuel in premixed as well as diffused zone. With increase in triacetin quantity in the blend fuel, deterioration of diffused combustion has taken place. The 5% triacetin blend fuel could not gain sensible heat from the air - fuel mixture and converse is true for the 10% blend fuel. There is dramatic change in the process, the coefficient with percentage of triacetin mix, especially at 5% and 10% which affects the C_p and C_v values. The cumulative heat release rate curves also exhibit the same in case of 5% and 10% triacetin blend fuels with an advantage to 10% triacetin blend fuel in diffused combustion zone. There is a rapid fall of heat release rate in case of 5% triacetin additive blend fuel.

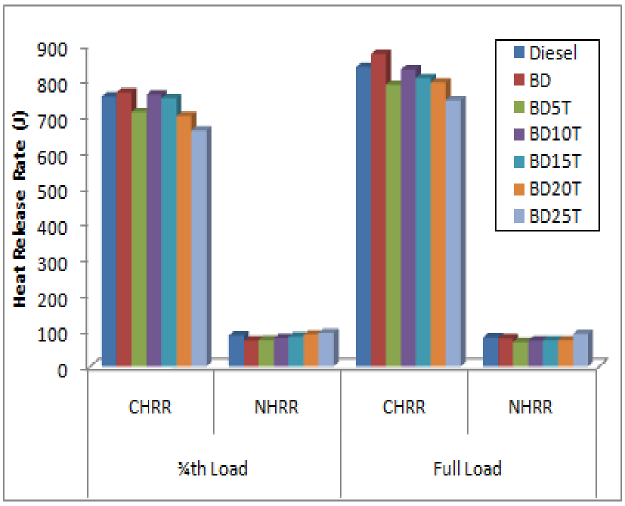

Fig. 8: Max. Values variation of CHRR and NHRR 75% and Full Load

4.3PERFORMANCE:

***4.3.1 Brake Thermal Efficiency & BSFC*:** Figure **9** gives the details of brake thermal efficiency and *bsfc* versus percentage of load for neat fuel and the blend fuels. It can be ascertained from the figure that is increasing with the triacetin additive percentage. The load and thermal efficiency, both will increase, but are governed by different equations entailing non-synchronous increase. The implicit parameter in thermal efficiency is Calorific Value, which decreases with the increase in fuel consumption, as the calorific value of triacetin is comparatively lesser. The 10% triacetin blend fuel yielded better thermal efficiency curve at higher loads as observed. Brake Specific Fuel Consumption envisages the performance of engine with different blend fuel samples. For 10% triacetin blend, the part load performance is observed better corroborating with the brake thermal efficiency results as described above.

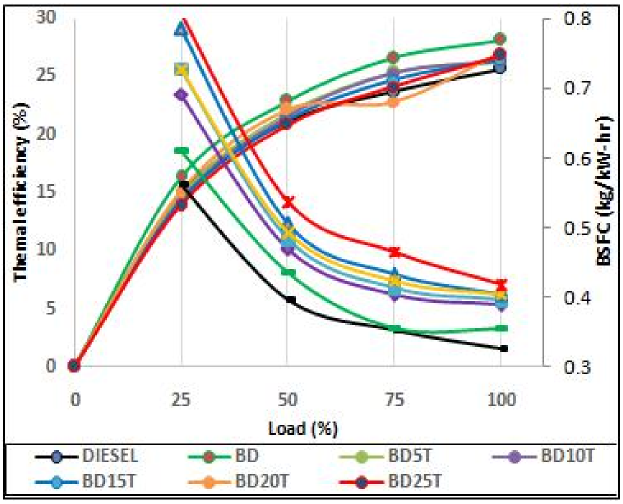

Fig. 9: Thermal Efficiency and BSFC vs. Load

4.3.2 Cylinder peak pressure and Imep: Combustion pressures in the combustion chamber have been recorded with respect to the TDC position. For specific study of the start of combustion and the specific heat of fuel mixture employed, small combustion duration from 350^0 to 400^0 which encompasses the TDC position in between at 360^0 has been chosen. There is relative pressure rise at the start of combustion due to temperature rise because of lower specific heat of mixture and higher convective heat transfer coefficient for various mixtures (Fig. **10**). Thermal properties of the bio-fuel change with the blending of soluble triacetin. The figure **11** shows blends with Triacetin produced IMEP lesser than 6.5 bar, eliminating them from the knocking zone. The 10% triacetin blend fuel, even though produced 7.2 bar IMEP, can be regarded as safe since it is marginally below the IMEP ranges of diesel and biodiesel in the 80% burnt mass fraction zone at 1500 rpm.

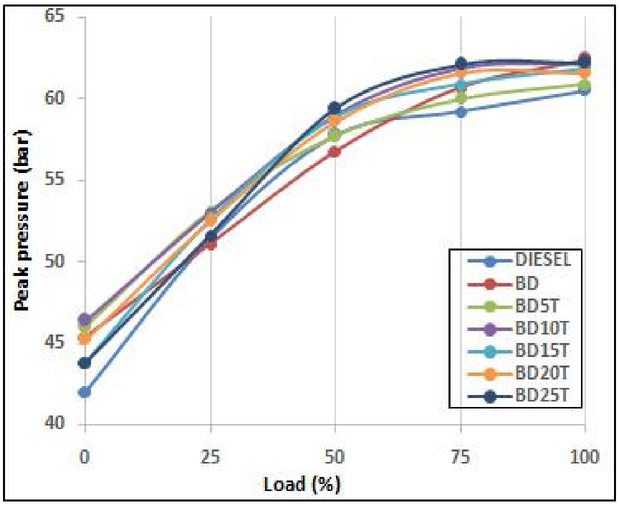

Fig. 10: Cylinder peak pressure vs. Load

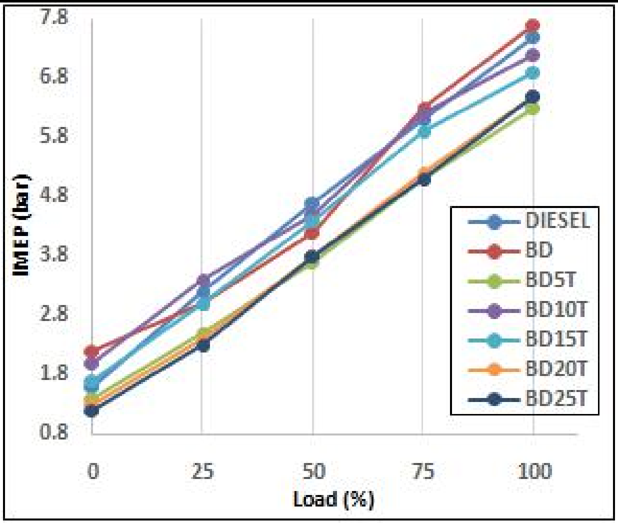

Fig. 11: IMEP vs. Load

***4.3.3 Exhaust Gas Temperature*:** Fromfigure **12**, there is marginal fall in the exhaust gas temperatures with respect to increase in the load on engine at higher percentages of triacetin and this may be because of lower heat release rate in the diffused combustion process at lower calorific value of the blended fuel.

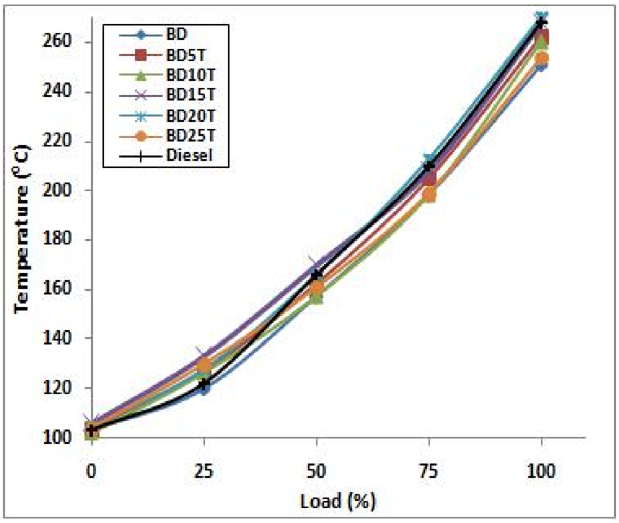

Fig. 12: Exhaust gas temperature vs. Load

4.4 EXHAUST EMISSIONS: Black color bars indicate the absolute values of the diesel fuel emissions and other negative side colored stalks indicates decrease from the absolute value of diesel. For example, in the figure **13**, blue stalk indicate HC emission of biodiesel at full load then the absolute value of HC emission for the biodiesel is 132-72= 60ppm. The extent of decrease in that particular emission value can be easily observed in the graph.

***4.4.1Hydrocarbon (HC) Emission*:** Hydrocarbon emissions decrease with the loading on engine and 10% triacetin blend produced remarkable value of decrease (99 ppm). Biodiesel is known for its efficiency to reduce emissions except NOx. Triacetin blend with biodiesel further helped in the reduction of HC by 27ppm. There is 75% maximum reduction in HC emission with the triacetin blending which can be observed from the figure **13**. As the load on the engine increases, the HC emission decreases at all percentages of blend fuels tested.

***4.4.2 Oxides of Carbon (CO & CO_2) Emissions*:** Carbon monoxide emissions (figure **14**) are reduced better at lower loads. It is observed that CO emission also reduced by maximum of 50% with the use of 90%BD + 10%T blend fuel and trade off with other emissions has not been observed. The CO_2 emissions reduction is nominal at all loads of the engine. From figure 1**5**, there is a reduction of nearly maximum 10% of CO_2 emission with this blend fuel and at higher loads.

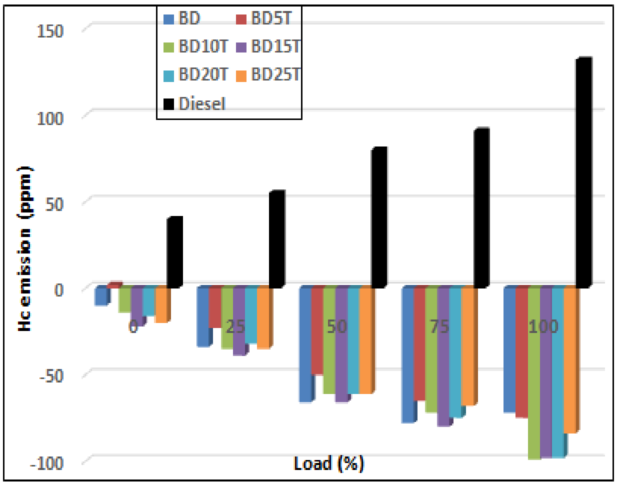

Fig.13: HC emission values vs. Load

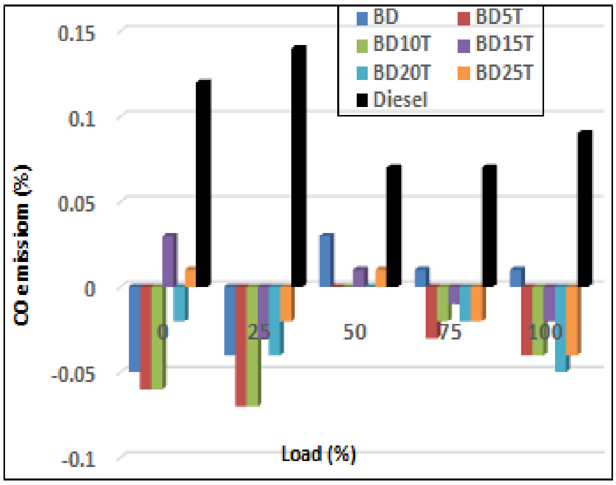

Fig. 14: CO emission values vs. Load

***4.4.3 Nitrogen Oxide (NO) Emission*:**NO emission trade off is not observed with HC emission because the figure

https://dx.doi.org/10.22161/ijaers.5.9.28 ISSN: 2349-6495(P) | 2456-1908(O)

16 envisage decrease of NO emission with the load and with the increase of triacetin percentage. For 10%

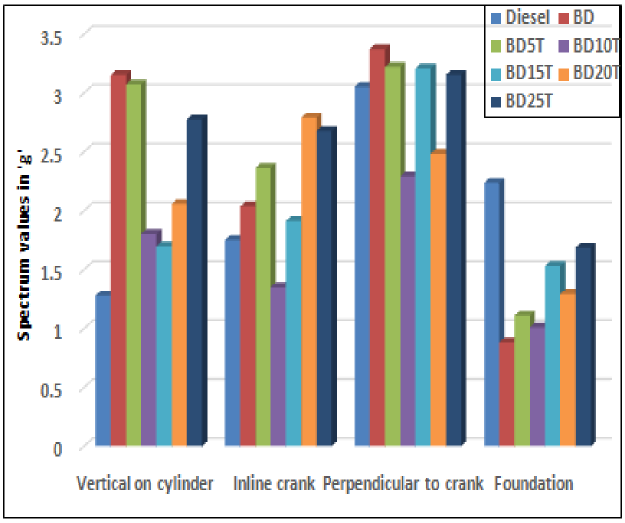

Fig. 18: Average spectrum values of the engine at full load

The FFT spectrums envisage the amplitudes of knocking frequencies with neat oils and with triacetin blends. The 10% triacetin blend fuel FFT spectrum (Figure **21**) indicates the knocking amplitude is minimum for the reading obtained on the engine cylinder head, in radial direction and in line crank shaft. This direction is chosen with the view that there won't be mixed effect like piston slap in other radial direction and thrust transfer to the piston in the vertical direction and thus knocking can be fully realized in the direction inline crank. The knocking frequencies are varying by little margin around 6500Hz because of the combustion temperature variation with respect to the blend combination of triacetin.

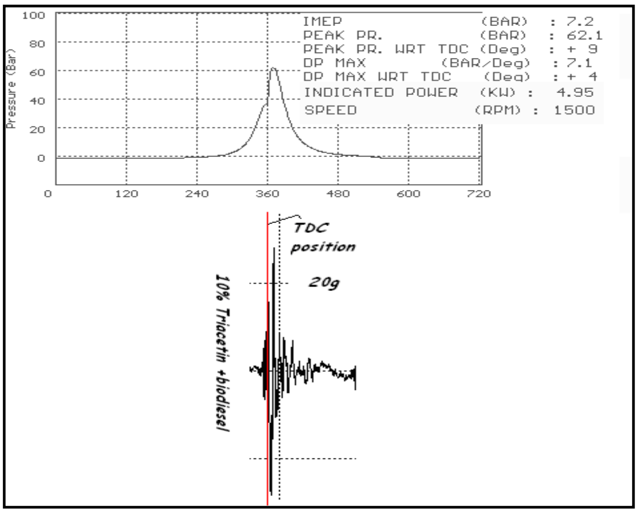

Fig. 19: Time wave recorded vertical on the cylinder head during explosion stroke at full load for 10% triacetin and 90% biodiesel

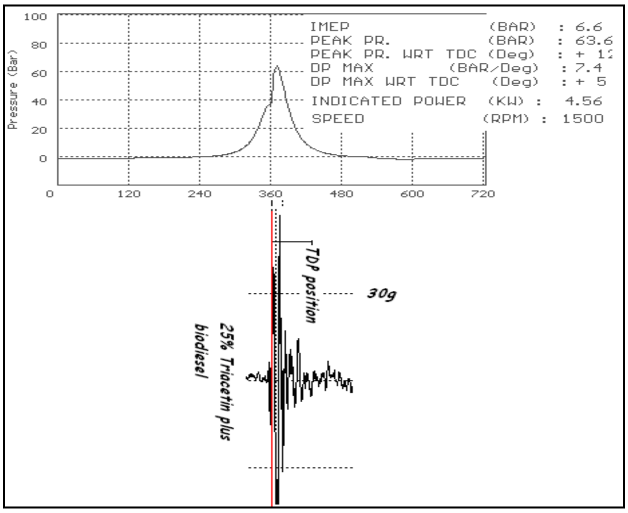

Fig. 20: Time wave recorded vertical on the cylinder head during explosion stroke at full load for 25% triacetin and 75% biodiesel

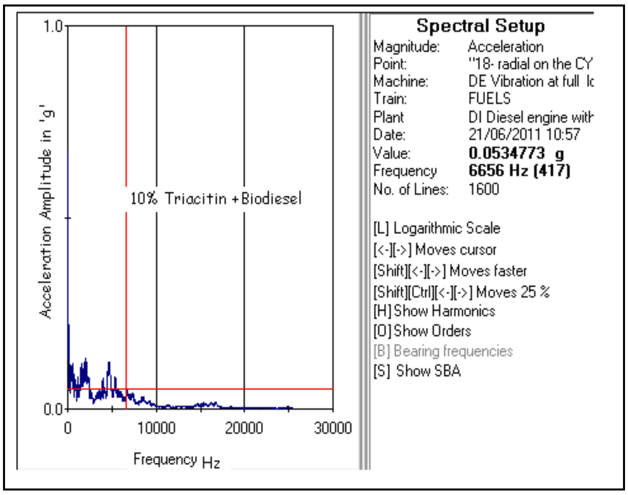

Fig. 21: FFT Spectrum Indicating Knocking Frequency and Acceleration Amplitude in Radial Direction of the Cylinder for 10% Triacetin + 90% Biodiesel Blend Fuel.

V. CONCLUSIONS

- The engine BSFC for 10% triacetin blend fuel at part load performance is better in the same way as in the case of brake thermal efficiency due the change of biodiesel properties with the addition of additive.
- The 10% triacetin blend, even though produced 7.2 bar IMEP, can be regarded as safe since it is marginally below the IMEP ranges of diesel and biodiesel in the 80% burnt mass fraction zone at 1500 rpm.
- The 10% blend of triacetin with biodiesel produced lowest amplitude at the knocking frequency

around 6,500Hz as observed from FFT graphs of the engine.

- Exhaust gas temperature reduces with increase in load at higher percentages of triacetin, because of lower heat release rates in the diffused combustion process by virtue of lower calorific value of the blended fuel.
- Maximum of 75% reduction in HC emission, 50% CO emission and 10% reduction of CO_2 emission is achieved at higher loads with 10% Triacetin additive- COME- blend fuel.
- Maximum of 28% to 29% decrease is obtained in NO emission at full load. It is obvious that there is no trade off between HC and NO, because both have decreased to cognizable extent.

REFERENCES

[1] Zhang J J., Huang Z., Wu J H., Qiao X Q., Fang J H., [2008], "Combustion and performance of heavy-duty diesel engines fuelled with dimethyl ether", *Inst. Mech. Engineers,* 222 (D), pp. 1691-1703.

[2] Iranmanesh M., Subrahmanyam J P., Babu M K J., [2008], "Potential of Diethyl ether as supplementary fuel to improve combustion and emission characteristics of diesel engines", SAE paper no: 2008-28-0044.

[3] Kapilan N., Mohanan P. and Reddy R P., [2008], "Performance and Emission Studies of Diesel Engine Using Diethyl Ether as Oxygenated Fuel Additive", SAE paper no: 2008-01-2466.

[4] Pinto A C., Guarieiro L L N., Rezende M J C., Ribeiro N M., Torres E A., Lopes W A., Pereira P A., de Andrade J. B., [2005], "Biodiesel: An over view", *Journal Brazilian Oil Chemists Society*, 16, pp.1313-1330.

[5] Pimentel M F., Ribeiro G M G S., Cruz R S., Stragevitch L., Pacheco Filho J G. A., Teixeira L S G., [2006], "Determination of Biodiesel Content When Blended With Mineral Diesel Fuel Using Infrared Spectroscopy and Multivariate Calibration",*Microchem Journal*,82, pp. 201-206.

[6] P. Venkateswara Rao and B. V. Appa Rao, [2018], "Heat release rate, performance and vibration analysis of diesel engine operating with biodiesel -Triacetin additive blend fuels", *International Journal of Automobile Engineering Research and Development*, 8(2), pp. 11-22.

[7] P. Venkateswara Rao and B. V. Appa Rao, [2012], "Heat release rate calculations and vibration analysis of DI-diesel engine operating with coconut oil methyl ester - triacetin additive blends", *The IUP Journal of Mechanical Engineering*, 5(2), pp. 43-57.

[8] Venkateswara Rao P., [2015], "Compression ratio effect on Diesel Engine working with Biodiesel (JOME)-Diesel blend as fuel", *Research Journal of Chemical Sciences,* 5(7), pp. 1-4.

[9] Bhatnagar A K., Kaul S., Chhibber V K., Gupta A K [2006], "HFRR studies on methyl esters of non edible oils", *Energy and Fuels*, 20, pp.1341-1344.

[10] Knothe G. and Steidley, K. R., [2005], "Lubricity of components of biodiesel and petrodiesel: The origin of biodiesel lubricity",*Energy and Fuels*, 19, pp.1192-1200.

[11] Labeckas G. and Slavinskas S. [2006], "The effect of rapeseed oil methyl ester on direct injection diesel engine performance and exhaust emissions", *Energy Conversion and Management*, 47, pp. 1954-1967.

[12] Ulrich a. And wichser a., [2003], "Analysis of additive metals in fuel and emission aerosols of diesel vehicles with and without particle traps", Anal. Bioanal. Chem., 377(1), pp. 71-81.

[13] Yanfeng G., Liu Shenghua Guo Hejun, Hu Tiegang, Zhou Longbao., [2007], "A new diesel oxygenate additive and its effects on engine combustion and emissions", *Applied Thermal Engineering*, 27, pp. 202-207.

[14] P. Venkateswara Rao and D. Prabhakara Chary, [2018], "Characteristics comparison of Biodiesel-Diesel Blend (B20) Fuel with Alcohol Additives", *International Journal of Advanced Engineering Research and Science*, (5)8, pp. 128.132,

[15] Jaichandar S., Annamalai K., [2011], "The status of biodiesel as an alternative fuel for diesel engine — An overview", *Journal of Sustainable Energy Environment*, 2, pp. 71-75.

[16] Usta N., Aydogan B., Con A H., Uguzdogam E., Ozkal S G., [2011], "Properties and quality verification of biodiesel produced from tobacco seed oil", *Energy Convers. Manag., 52*, pp. 2031-2039.

[17] P. Venkateswara Rao and S. Ramesh, [2015], "Optimization of Biodiesel production parameters (Pongamia pinnata oil) by transesterification process", *Journal of Advanced & Applied Sciences*, 3(3), pp. 84-88.

[18] Venkateswara Rao P., [2016], "Performance Analysis of D I Diesel Engine Fuelled with Diesel – Biodiesel (Methyl/Ethyl Esters) of non-edible oil blends", *International Journal of Research – Granthaalayah*, 4 (7) pp. 20-26.